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(54) **Optical compensator for improved gray scale performance in liquid crystal display.**

(57) A liquid crystal display for viewing at various angles with respect to a normal axis perpendicular to the display includes a polarizer layer having an absorbing axis, an analyzer layer having an absorbing axis substantially perpendicular to the absorbing axis of the polarizer layer, a liquid crystal layer disposed between the polarizer layer and the analyzer layer and having a director exhibiting an azimuthal twist through the layer with respect to the normal axis, a first electrode proximate to a first major surface of the liquid crystal layer, a second electrode proximate to a second major surface of the liquid crystal layer, the first and second electrodes being adapted to apply a voltage across the liquid crystal layer when the electrodes are connected to a source of electrical potential, and a compensator, including a positively birefringent O-plate compensator layer disposed between the polarizer layer and the analyzer layer with its principal symmetry axis oriented at a substantially oblique angle with respect to the normal axis.

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BACKGROUND OF THE INVENTION

This invention is concerned with the design of liquid crystal displays and particularly with techniques for maximizing the field of view of such displays by maintaining a high contrast ratio and minimal variance in relative gray levels over a wide range of viewing angles.

Liquid crystals are useful for electronic displays because polarized light traveling through a liquid crystal layer is affected by the layer's birefringence, which can be changed by the application of a voltage across the layer. By using this effect, the transmission or reflection of light from an external source, including ambient light, can be controlled with much less power than is required for the luminescent materials used in other types of displays. As a result, liquid crystal displays are now commonly used in a wide variety of applications, such as, for example, digital watches, calculators, portable computers, and many other types of electronic equipment, exhibiting in these applications the advantages of very long life and operation with very low weight and low power consumption.

The information content in many liquid crystal displays is presented in the form of multiple rows of numerals or characters, which are generated by segmented electrodes deposited in a pattern on the display. The electrode segments are connected by individual leads to electronic driving circuitry, which causes the desired information to be displayed by applying a voltage to the appropriate combination of segments, thereby controlling the light transmitted through the segments. Graphic and television displays may be achieved by employing a matrix of pixels in the display which are connected by an X-Y sequential addressing scheme between two sets of perpendicular conductors. More advanced addressing schemes, applied predominantly to twisted nematic liquid crystal displays, use arrays of thin film transistors to control driving voltages at the individual pixels.

Contrast and stability of relative gray scale intensities are important attributes in determining the quality of a liquid crystal display. The primary factor limiting the contrast achievable in a liquid crystal display is the amount of light which leaks through the display in the dark state. In addition, the contrast ratio of the liquid crystal device also depends on the viewing angle. The contrast ratio in a typical liquid crystal display is a maximum only within a narrow viewing angle centered about normal incidence and drops off as the angle of view is increased. This loss of contrast ratio is caused by light leaking through the black state pixel elements at large viewing angles. In color liquid crystal displays, such leakage also causes severe color shifts for both saturated and gray scale colors. The viewing zone of acceptable gray scale stability in a typical prior art twisted nematic liquid crystal display is severely limited because, in addition to color shifts caused by dark state leakage, the optical anisotropy of the liquid crystal molecules results in large variations in gray level transmission, i.e., a shift in the brightness-voltage curve, as a function of viewing angle. The variation is severe enough that, at extreme vertical angles, some of the gray levels reverse their transmission levels. These limitations are particularly important for applications requiring a very high quality display, such as avionics, where viewing of cockpit displays from both pilot and copilot seating positions is important. Such high information content displays require that the relative gray level transmission be as invariant as possible with respect to viewing angle. It would be a significant improvement in the art to provide a liquid crystal display capable of presenting a high quality, high contrast image over a wide field of view.

SUMMARY OF THE INVENTION

The compensator design of this invention, which includes a positively birefringent O-plate layer with a special orientation, makes possible a significant improvement in the gray scale properties and contrast ratios of liquid crystal displays over a wide range of viewing angles. A liquid crystal display for viewing at various angles with respect to a normal axis perpendicular to the display includes a polarizer layer having an absorbing axis, an analyzer layer having an absorbing axis substantially perpendicular to the absorbing axis of the polarizer layer, a liquid crystal layer disposed between the polarizer layer and the analyzer layer and having a director exhibiting an azimuthal twist through the layer with respect to the normal axis, a first electrode proximate to a first major surface of the liquid crystal layer, a second electrode proximate to a second major surface of the liquid crystal layer, the first and second electrodes being adapted to apply a voltage across the liquid crystal layer when the electrodes are connected to a source of electrical potential, and a compensator, including a positively birefringent O-plate compensator layer disposed between the polarizer layer and the analyzer layer with its principal symmetry axis oriented at a substantially oblique angle with respect to the normal axis.

In a more particular embodiment, the principal symmetry axis of the O-plate layer is further oriented approximately perpendicular to the orientation of the average liquid crystal director in the central region of

the liquid crystal layer at a voltage in the gray scale transition region of the BV curve for the liquid crystal layer.

In an alternative embodiment, the principal symmetry axis of the O-plate layer is further oriented at an angle with respect to the normal axis that is approximately equal to the orientation angle with respect to the normal axis of the average liquid crystal director in the central region of the liquid crystal layer at a voltage in the gray scale transition region of the BV curve for the liquid crystal layer and wherein the azimuthal orientation of the principal symmetry axis of the O-plate layer about the normal axis is rotated approximately 180° with respect to the azimuthal orientation of the average liquid crystal director.

The compensator may also include one or more positively birefringent A-plate compensator layers, each A-plate layer being oriented with its optic axis relative to the optic axis of an O-plate layer such that retardation of light passing through the compensator at normal incidence is minimized.

In addition, one or more negatively birefringent C-plate compensator layers may be added to the compensator.

The O-plate layer may be joined by a second positively birefringent O-plate compensator layer with its optic axis oriented at a substantially oblique angle with respect to the normal axis and such that the azimuth angles of the first and second O-plate layers are crossed, the two O-plates thereby constituting crossed O-plates.

DESCRIPTION OF THE DRAWINGS

Figure 1 depicts the coordinate system that is used to specify component orientations in the description of this invention.

Figure 2 is a cross sectional schematic side view of a 90° twisted nematic, transmissive type normally white liquid crystal display (LCD) constructed according to this invention.

Figure 3 is a plot of the tilt angle of the director (in degrees along the vertical axis) as a function of position (as a fraction z of depth along the horizontal axis) in a 90° twisted nematic liquid crystal cell.

Figure 4 is a related plot for the same cell depicting the twist angle of the liquid crystal molecules as a function of position in the cell.

Figure 5 is a plot of calculated brightness vs. voltage (BV) electrooptic curves at a variety of horizontal viewing directions for a typical twisted nematic display without the benefit of the gray scale improvements provided by this invention.

Figure 6 is a plot of calculated brightness vs. voltage (BV) electrooptic curves at a variety of vertical viewing directions for a typical twisted nematic display without the benefit of the gray scale improvements provided by this invention.

Figure 7 is an illustration of the viewer's perspective relative to the average director orientation of a liquid crystal.

Figure 8 is a schematic, expanded view of a gray scale compensator with an AOC-LC-CO configuration constructed according to the present invention.

Figure 9 is a plot of transmitted light as a function of voltage illustrating the BV characteristics at a variety of horizontal viewing angles for the compensator configuration depicted in Figure 8.

Figure 10 is a plot of transmitted light as a function of voltage illustrating the BV characteristics at a variety of vertical viewing angles for the compensator configuration depicted in Figure 8.

Figure 11 is a plot as a function of vertical and horizontal viewing angle depicting calculated isocontrast contours for the compensator configuration depicted in Figure 8.

Figure 12 is a schematic, expanded view of a gray scale compensator with an A-OxO-A-LC configuration constructed according to the present invention.

Figure 13 is a plot of transmitted light as a function of voltage illustrating the BV characteristics at a variety of horizontal viewing angles for the compensator configuration depicted in Figure 12.

Figure 14 is a plot of transmitted light as a function of voltage illustrating the BV characteristics at a variety of vertical viewing angles for the compensator configuration depicted in Figure 12.

Figure 15 is a plot as a function of vertical and horizontal viewing angle depicting calculated isocontrast contours for the compensator configuration depicted in Figure 12.

Figure 16 is a schematic, expanded view of a gray scale compensator with an O-A-LC configuration constructed according to the present invention.

Figure 17 is a plot of transmitted light as a function of voltage illustrating the BV characteristics at a variety of horizontal viewing angles for the compensator configuration depicted in Figure 16.

Figure 18 is a plot of transmitted light as a function of voltage illustrating the BV characteristics at a variety of vertical viewing angles for the compensator configuration depicted in Figure 16.

Figure 19 is a plot as a function of vertical and horizontal viewing angle depicting calculated isocontrast contours for the compensator configuration depicted in Figure 16.

DESCRIPTION OF THE INVENTION

When viewed directly a twisted nematic liquid crystal display provides high quality output, but at large viewing angles the image tends to degrade and exhibit poor contrast and gray scale nonuniformity. This occurs because the phase retardation effect of the liquid crystal material on light passing through it inherently varies with the inclination angle of the light, leading to a lower quality image at large viewing angles. By introducing one or more optical compensating elements in conjunction with the liquid crystal cell, however, it is possible to substantially correct for the undesirable angular effects and thereby maintain higher contrast and stable relative gray scale intensities at larger viewing angles than otherwise possible.

In a "normally white" display configuration, the 90° twisted nematic cell is placed between polarizers which are crossed, such that the transmission axis of each polarizer is either parallel or perpendicular to the director orientation of the liquid crystal molecules in the region of the cell adjacent to that polarizer. The "nonselect" (no applied voltage) areas appear light in a normally white display, while "select" areas (those which are energized by an applied voltage) appear dark. In the select areas the liquid crystal molecules tend to tilt and rotate toward alignment with the applied electric field. If this alignment were perfectly homeotropic, all the liquid crystal molecules in the cell would be oriented with their long axes normal to the substrate glass. Because the liquid crystals used for twisted nematic displays exhibit positive birefringence, this arrangement, known as the homeotropic configuration, would exhibit the optical symmetry of a positively birefringent C-plate. A C-plate is a uniaxial birefringent plate with its extraordinary axis (i.e., its optic or c-axis) perpendicular to the surface of the plate (parallel to the direction of normally incident light). In the select state the liquid crystal in a normally white display would thus appear isotropic to normally incident light, which would be blocked by the crossed polarizers.

One reason for the loss of contrast with increased viewing angle which occurs in a normally white display is that a homeotropic liquid crystal layer will not appear isotropic to off-normal light. Light propagating through the layer at off-normal angles appears in two modes due to the birefringence of the layer; a phase delay is introduced between those modes and increases with the incident angle of the light. This phase dependence on incidence angle introduces an ellipticity to the polarization state which is incompletely extinguished by the second polarizer, giving rise to light leakage. To correct for this effect, an optical compensating element must also have C-plate symmetry, but with negative ($n_e < n_o$) birefringence. Such a compensator will introduce a phase delay opposite in sign to the phase delay caused by the liquid crystal layer, thereby restoring the original polarization state and allowing light passing through energized areas of the layer to be blocked more completely by the output polarizer. C-plate compensation, however, does not impact the variation of gray scale with viewing angle, which is addressed by the present invention.

Figure 1 depicts the coordinate system which is used to describe the orientation of both liquid crystal and birefringent compensator optic axes. Light propagates toward the viewer 102 in the positive z direction 104 which, together with the x-axis 106 and the y-axis 108, form a right-handed coordinate system. Backlighting is provided, as indicated by the arrows 112, from the negative z direction. The polar or tilt angle (θ) is defined as the angle between the molecular optic axis $\hat{c}$ and the x-y plane, measured from the x-y plane. The azimuthal or twist angle (Φ) is measured from the x-axis to the projection 110 of the optic axis into the x-y plane.

Figure 2 is a cross sectional schematic side view of a twisted nematic, transmissive type normally white liquid crystal display (LCD) constructed according to this invention. The display includes a polarizer layer 222 and an analyzer layer 224, between which is positioned a liquid crystal layer 226, consisting of a liquid crystal material in the nematic phase. It is convenient in describing the compensation elements of this invention to refer to a normal axis perpendicular to the display, which is depicted by a dashed line 427. The polarizer and the analyzer, as is indicated by the symbols 228 (representing a polarization direction in the plane of the drawing) and 230 (representing a polarization direction orthogonal to the plane of the drawing), are oriented with their polarization directions at 90° to one another, as is the case for a normally white display. A first transparent electrode 212 and a second transparent electrode 214 are positioned adjacent to opposite surfaces of the liquid crystal layer so that a voltage can be applied, by means of a voltage source 236, across the liquid crystal layer. The liquid crystal layer is in addition sandwiched between a pair of glass plates 238 and 240. As is explained further below, the inner surfaces of the glass plates 238 and 240, which are proximate to the liquid crystal layer 226, are physically or chemically treated, as by buffing.

As is well known in the LCD art (see, e.g., Kahn, The Molecular Physics of Liquid-Crystal Devices, Physics Today, Page 68 (May 1982)), when the material of the liquid crystal layer 226 is in the nematic

phase and the inner surfaces of the plates 238 and 240 (the surfaces adjacent to the layer 226) are coated with a surface treatment for aligning the liquid crystal such as polyimide, buffed, and oriented with their buffed directions perpendicular, the director **n** of the liquid crystal material, absent any applied electrical voltage, will tend to align with the buffed direction (known as the "rub direction") in the regions of the layer proximate each of the plates 238 and 240. Furthermore, the director will twist smoothly with respect to the normal axis through an angle of 90° along a path in the layer 226 from the first major surface adjacent to the plate 238 to the second major surface adjacent to the plate 240. Consequently, in the absence of an applied electric field the direction of polarization of incoming polarized light will be rotated by 90° in traveling through the liquid crystal layer. When the glass plates and the liquid crystal layer are placed between crossed polarizers, such as the polarizer 228 and the analyzer 230, light polarized by the polarizer 228 and traversing the display, as exemplified by the light ray 246, will thus be aligned with the polarization direction of the analyzer 230 and therefore will pass through the analyzer. When a sufficient voltage is applied to the electrodes 212 and 214, however, the applied electric field causes the director of the liquid crystal material to tend to align parallel to the field. With the liquid crystal material in this state, light passed by the polarizer 228, as illustrated by the light ray 248, will be extinguished by the analyzer 230. Thus an energized pair of electrodes will produce a dark region of the display, while light passing through regions of the display which are not subject to an applied field will produce illuminated regions. As is well known in the LCD display art, an appropriate pattern of electrodes, activated in selected combinations, can be utilized in this manner to display alphanumeric or graphic information. As explained further below, one or more compensator layers, such as the layers 250 and 252, may be included in the display to improve the quality of the display.

Figure 3 is a calculated plot of liquid crystal director tilt as a function of position in the liquid crystal layer (where the cell gap has been normalized to unity) in a 90 degree twisted nematic cell. It illustrates the typical distribution of molecular tilt angles when no voltage is applied (curve 302), under a typical select state voltage (curve 304), and under the application of several intermediate voltages chosen to yield linearly spaced gray levels (curves 306, 308, 310, 312, 314, and 316). Note that the gray level curves are centered about a tilt angle of approximately 45° halfway through the cell.

Figure 4 is a related plot for the same cell depicting the calculated twist angle of the liquid crystal molecules as a function of position in the cell. When there is no applied voltage, the twist is distributed evenly throughout the cell (straight line curve 402). Under a fully select state voltage, the twist angles are distributed as shown by the extremal, S-shaped curve 404. The twist distributions for gray levels are shown by the intermediate curves between these two curves.

As illustrated by Figures 3 and 4, when the fully selected voltage is applied nearly all of the twist experienced by the liquid crystal molecules, and a substantial portion of the tilt, occurs in the central region of the cell. Because of these phenomena, the continuous variation of molecular orientation within the cell can be separated into three regions, each of which is characterized by its own optical symmetry. Thus the central regions 318 (Figure 3) and 418 (Figure 4) can be considered as nominally homeotropic in the fully select state, approximating the properties of a C-plate. The regions 320 and 322 (Figure 3) and 420 and 422 (Figure 4), near each surface of the cell, behave as A-plates, each with its extraordinary axis aligned with the rub direction of the proximate substrate. Because there is essentially no twist in the molecules of the regions 320, 322, 420, and 422, these molecules are essentially aligned with the respective rub directions on either side of the liquid crystal layer. In addition, because the twist angle of the molecules in the regions 320 and 420 tends to be perpendicular to the twist angle of the molecules in the regions 322 and 422, the effect of these two regions on light traveling through the cell tends to be canceled, leaving the middle C-plate region to exert the dominant influence.

A negative C-plate compensator is designed to correct for the angle dependent phase shift introduced by propagation through the central, approximately C-plate region. Such a compensator is effective to the extent that the optical symmetry of this region dominates the selected state of the liquid crystal cell, that is, the extent to which the molecules align with the applied field. This implies that negative C-plate compensation will work best when strong fields are used for the energized state as this makes the homeotropic approximation more nearly correct. The use of a C-plate has been demonstrated to significantly reduce the leakage of the dark state over an extended field of view, thus improving contrast and reducing color desaturation.

While the use of the C-plate compensator is important for eliminating color desaturation, the issue of gray scale is independent. The problem of gray scale linearity over the field of view relates entirely to the brightness level changes for levels assigned between the select (black for a normally white display) and nonselect (white for a normally white display) states. Consider the brightness versus voltage (BV) electrooptic response curves for a display to which eight gray levels are assigned, from level 0, the select

black state, to level 7, the nonselect white state. Gray levels between 0 and 7 are chosen by assigning them a set of voltages spaced linearly in brightness along the BV curve between the select and nonselect voltages.

Figure 5 is a plot of calculated BV curves for a normally white, 90° twisted nematic display as the horizontal viewing angle varies from zero to 50° in 10° increments while the vertical viewing angle remains fixed at zero. (The change in the BV curves with horizontal angle is independent of whether the horizontal deviation is to the left or right.) Note that the regions of each curve over which gray levels would be selected almost overlie one another for the various horizontal angles. This means that gray levels chosen to be linearly spaced at zero degrees would remain very nearly linear at even high horizontal viewing angles.

The gray scale linearity problem appears when the vertical viewing angle varies. This is illustrated in Figure 6, which is a plot of the BV curves for a normally white, 90° twisted nematic display as the vertical viewing angle varies from -30° to +30° while the horizontal viewing angle remains fixed at zero. It can be observed that for angles below 0° (measured from the normal) the BV curves shift to the right (higher voltage), and fall monotonically from their maximum but fail to reach zero.

For angles above normal, the curves shift to the left and develop a rebound after an initial minimum. These effects can be explained by considering the perspectives of viewers looking at the display from above, at, and below normal, as shown in Figure 7. The critical feature is the relationship between the light traveling towards the viewer and the average liquid crystal director tilt at the center of the cell as voltage is increased.

As the voltage is increased the average liquid crystal director in the center of the cell tilts from a parallel orientation 702 toward a homeotropic one 704. For the viewer at normal incidence, retardation is highest at the nonselect state voltage and lowest at the select state voltage. When the anisotropy is zero, the polarization state of the light is unchanged and it is blocked by the analyzer. Thus the viewer sees a monotonic decrease in brightness to zero with increasing voltage. Now consider the case of the positive vertical viewing direction (viewer above normal incidence). At some intermediate voltage the average director 706 points toward the viewer and the retardation is minimal. Here the viewer sees a brightness with voltage that initially decreases, but then reaches a minimum at the point of minimal retardation and then increases.

For the negative vertical viewing direction (viewer below normal incidence) the average director always presents a large anisotropy to the light ray, even at the highest voltage. The viewer therefore sees a monotonic decrease in brightness. Furthermore, the average liquid crystal director is always oriented at a larger angle with respect to the light ray for the below normal viewer than it is for the normal incidence viewer. Therefore the anisotropy is greater and the brightness level is always higher in the negative vertical viewing direction than it is at normal incidence.

This dependency of the BV curves on vertical angle has a profound impact on gray scale linearity. Note that a voltage chosen to yield a 50 per cent gray level on the 0 degree curve in Figure 6 yields a dark state on the +30 degree curve and a fully white state at -30 degrees.

To eliminate reversal of gray levels and improve gray scale stability, it is an outstanding feature of this invention to provide a compensator which includes a birefringent O-plate compensator layer. The O-plate compensator of this invention utilizes a positive birefringent material with its principal optic axis oriented at a substantially oblique angle with respect to the plane of the display (hence the term "O-plate"). "Substantially oblique" implies an angle appreciably greater than 0° and less than 90°. O-plates have been utilized, for example, with angles relative to the plane of the display between 35° and 55°, typically at 45°. Moreover, O-plates with either uniaxial or biaxial materials can be used. The O-plate of this invention can be placed in a variety of locations between the polarizer layer and the analyzer layer.

The gray scale compensator of this invention may also include, in more particular embodiments, A-plates and/or negative C-plates. An A-plate is a birefringent layer with its extraordinary axis (i.e., its c-axis) oriented parallel to the surface of the layer. Its A-axis is thus oriented normal to the surface (parallel to the direction of normally incident light), leading to its designation as an A-plate. A-plates may be fabricated by the use of uniaxially stretched polymer films, such as polyvinyl alcohol, or other suitably oriented organic birefringent materials. A C-plate is a uniaxial birefringent layer with its extraordinary axis oriented perpendicular to the surface of the layer (parallel to the direction of normally incident light). Negatively birefringent C-plates may be fabricated by the use of uniaxially compressed polymers (See, e.g., Clerc, U.S. Patent No. 4,701,028), stretched polymer films, or by the use of physical vapor deposited inorganic thin films (See, e.g., Yeh, U.S. Patent No. 5,196,953), for example.

Oblique deposition of a thin film by physical vapor deposition (see, e.g., Motohiro, Applied Optics, Volume 28, Pages 2466-2482(1989)), can be used to fabricate O-plate components. Such components are by their nature biaxial. The growth characteristics generate a microscopic columnar structure. The angles of

the columns are tipped in the direction of the arrival of the vapor stream. A deposition angle (measured from normal) of 76°, for example, results in a column angle of approximately 45°. The columns develop an elliptical cross section as the result of shadowing. This elliptical cross section is what gives rise to the biaxial character of the films. The birefringence, in magnitude and symmetry, is entirely attributable to the film microstructure and is referred to as form birefringence. These phenomena in thin films have been extensively studied and described by Macleod, Structure-related Optical Properties of Thin Films, J. Vac. Sci. Technol. A, Volume 4, No. 3, Pages 418-422(1986).

Uniaxial O-plate components similarly offer numerous solutions which in general have superior performance. These may be fabricated by the use of suitably oriented organic birefringent materials. Those skilled in the art will recognize other means for fabricating both uniaxial and biaxial O-plates.

The O-plate in the compensator of this invention is oriented with its principal symmetry axis at a substantially oblique angle with respect to the normal. In a particular embodiment, this orientation angle is nominally equal to the orientation of the average liquid crystal director in the central region of the liquid crystal layer at a voltage in the gray scale transition region of the BV curve. Furthermore, in a particular embodiment the azimuthal orientation of the principal symmetry axis is rotated with respect to that of the liquid crystal director by nominally 180°. The O-plate axis in this embodiment is thus oriented approximately perpendicular to the average liquid crystal director in the center of the cell. The compensator may be further configured such that it introduces no retardation for light traversing the cell at normal incidence. This is accomplished by combining the O-plate with a positively birefringent A-plate, with their optic axes nominally at right angles. Their retardations and relative angles are selected to cancel their retardation at normal incidence.

Elimination of gray scale reversal by the use of this gray scale compensation layer occurs in the following manner. In the positive vertical viewing direction, the retardation of the O-plate increases with viewing angle and tends to offset the decreasing retardation of the liquid crystal layer. When the viewer is looking down the axis of the average liquid crystal director, the presence of the O-plate prevents the layers between the two polarizers from appearing isotropic. Thus the rebound in the BV curve, shown in Figure 6, is reduced and moved to higher voltages outside of the gray scale voltage range.

In the negative vertical viewing direction, the combination of an O-plate and an A-plate with their optic axes nominally at right angles tends to exhibit birefringence characteristics similar to that of a negative birefringence retarder with its optic axis oriented perpendicular to the plane containing the axes of the O-plate and A-plate. The direction of this retarder axis is nominally parallel to the orientation of the average liquid crystal in the central region of the cell when it is driven at a voltage between select and nonselect states. The presence of an O-plate oriented in this manner thus tends to cancel the birefringence of the liquid crystal layer, pulling the BV curve down, or equivalently, moving it toward the direction of lower voltages (i.e., left). A similar effect occurs in the positive and negative horizontal viewing directions as well.

The overall effect of introducing the O-plate compensator of this invention in this manner is to eliminate large rebounds in the gray scale voltage region and reduce the left-to-right shift in the BV curves as the viewing angle is varied from negative to positive vertical angles. The orientations of the compensator optic axes are carefully chosen so that the combined retardation effects cancel each other in the normal incidence viewing direction as well as minimize rebounds in the horizontal viewing direction. Combinations of more than one O-plate can be used as long as their orientations satisfy these requirements. Furthermore, negative C-plates can, for certain configurations, increase the contrast ratio at large fields of view, occasionally with some decrease in gray scale linearity.

The liquid crystal layer, the compensator layers, and the polarizer and analyzer layers may assume a variety of orientations relative to one another in implementing embodiments of the invention using oblique retarders. Some of the possible configurations which have been considered are set out in Table I, where A represents an A-plate, C represents a C-plate, O represents an O-plate, LC represents the liquid crystal, and OxO represents crossed O-plates. Crossed O-plates are adjacent O-plates with their azimuth angles Φ - (as defined in Figure 1) nominally crossed, one oriented between 0° and 90°; and the second oriented between 90° and 180°.

Table I

<--------------Rear (Source Side)   Front (Viewer Side)-------------->

	O	A	LC		
	A	O	LC		
		O	LC	O	A
A	O	A	LC		
	O	A	LC	A	
O	A	C	LC		
	OxO	A	LC		
A	OxO	A	LC		

			A	LC	OxO	A	
A	O	A	C	LC			
		A	O	LC	O	A	
	A	O	C	LC	C	O	
	A	O	C	LC	C	O	A
	C	A	O	LC	O	A	C

The projections of the principal axes onto the plane of the display with respect to the liquid crystal director can vary with the embodiment. In some cases, for example with two O-plates, the O-plate axis projections are at 45° with respect to the average liquid crystal director, while in others, the O-plate axis is parallel with the liquid crystal director.

OxO (crossed O-plate) designs that are further compensated with A-plates provide additional design flexibility. The choice of A-plate value is not critical as such designs can be adjusted by varying the relative orientations of the A-plates. Thus it is possible to generate desired solutions with commercially available A-plate retardation values.

Figures 8-19 illustrate several possible gray scale compensation configurations according to this invention, including symmetric, asymmetric, and crossed O-plate configurations. These figures show, for each embodiment, the component configuration, the BV characteristics for both vertical and horizontal viewing angles, and calculated isocontrast curves. Figures 8 - 11 show an asymmetric configuration with an A-plate, O-plate, and C-plate on one side of the liquid crystal layer, and a C-plate and O-plate on the opposite side (A-O-C-LC-C-O). Figures 12 - 15 show a configuration using crossed O-plates on one side of the liquid crystal layer (A-OxO-A-LC). Finally, Figures 16 - 19 show a simple configuration with only two compensator components, one O-plate and one A-plate on one side of the liquid crystal layer (O-A-LC).

The flexibility which the oblique compensation scheme of this invention offers the display designer allows tailoring of performance to specific display product requirements. It is possible, for example, with simple configuration and parameter modifications to achieve isocontrast optimized for left or right viewing, isocontrast optimized for extreme vertical angle viewing, or isocontrast optimized for viewing at both large left and right angles above normal viewing. It is also possible to adjust the configuration and parameters to

improve both field of view and grayscale linearity, or to further optimize one at the expense of the other. Furthermore, a negatively birefringent A-plate may be substituted for a positive A plate. In this case, the negatively birefringent A-plate would be oriented with its extraordinary axis perpendicular to the orientation appropriate for a positively birefringent A-plate. Additional changes would also be required in the other components of the compensator to optimize performance when a negative A-plate is used.

The preferred embodiments of this invention have been illustrated and described above. Modifications and additional embodiments, however, will undoubtedly be apparent to those skilled in the art. Another possible embodiment, for example, would utilize the compensator layers as one or more of the substrates in the display structure. Furthermore, this invention is applicable to liquid crystal displays other than 90° twisted nematic, as long as gray scale is achieved through a tilted director configuration. The invention is applicable as well to color displays, in which color filters are associated with the arrays of electrodes in the display. Furthermore, equivalent elements may be substituted for those illustrated and described herein, parts or connections might be reversed or otherwise interchanged, and certain features of the invention may be utilized independently of other features. In addition, details of the liquid crystal display, such as active matrix circuitry, are not presented because such details are well known in the art of liquid crystal displays. Consequently, the exemplary embodiments should be considered illustrative, rather than inclusive, while the appended claims are more indicative of the full scope of the invention.

The teaching of the following documents, which are referred to herein, is incorporated by reference:

Clerc, U.S. Patent No. 4,701,028

Clerc, Vertically Aligned Liquid-Crystal Displays, SID 91 Digest, Pages 758-761 (Society for Information Display 1991);

Gooch, et al., The Optical Properties of Twisted Nematic Liquid Crystal Structures with Twist Angles ≤ 90°, Journal of Physics D, Volume 8, Page 1575(1975);

Hatoh, et al., Viewing Angle Magnification in a TN LCD with an Ultra-Super-Twisted Liquid Crystal Compensator;

Iieda, et al., Color Compensation Plate for Liquid-Crystal Display, Japan Kokai Tokkyo Koho No. JP 03028822 A2 (7 Feb 1991);

Kahn, The Molecular Physics of Liquid-Crystal Devices, Physics Today, Page 68 (May 1982);

Macleod, Structure-related Optical Properties of Thin Films, J. Vac. Sci. Technol. A, Volume 4, No. 3, Pages 418-422(1986);

Motohiro, et al., Thin Film Retardation Plate by Oblique Deposition, Appl. Opt., vol. 28, No. 13, Pages 2466-2482(1989);

Yamamoto, et al., Full-Cone Wide-Viewing-Angle Multicolor CSH-LCD, SID 91 Digest, Pages 762-765 (Society for Information Display 1991); and

Yeh, et al., "Compensator for Liquid Crystal Display", U.S. Patent No. 5,196,953.

Claims

1. A liquid crystal display for viewing at various angles with respect to a normal axis perpendicular to the display, comprising:

   a polarizer layer having an absorbing axis;

   an analyzer layer having an absorbing axis substantially perpendicular to the absorbing axis of the polarizer layer;

   a liquid crystal layer disposed between the polarizer layer and the analyzer layer and having a director exhibiting an azimuthal twist through the layer with respect to the normal axis;

   a first electrode proximate to a first major surface of the liquid crystal layer; a second electrode proximate to a second major surface of the liquid crystal layer,

   the first and second electrodes being adapted to apply a voltage across the liquid crystal layer when the electrodes are connected to a source of electrical potential; and

   a compensator, including a positively birefringent O-plate compensator layer disposed between the polarizer layer and the analyzer layer with its principal symmetry axis oriented at a substantially oblique angle with respect to the normal axis.

2. The liquid crystal display of Claim 1, wherein the principal symmetry axis of the O-plate layer is further oriented approximately perpendicular to the orientation of the average liquid crystal director in the central region of the liquid crystal layer at a voltage in the gray scale transition region of the BV curve for the liquid crystal layer.

3. The liquid crystal display of Claim 1, wherein the principal symmetry axis of the O-plate layer is further oriented at an angle with respect to the normal axis that is approximately equal to the orientation angle with respect to the normal axis of the average liquid crystal director in the central region of the liquid crystal layer at a voltage in the gray scale transition region of the BV curve for the liquid crystal layer and wherein the azimuthal orientation of the principal symmetry axis of the O-plate layer about the normal axis is rotated approximately 180° with respect to the azimuthal orientation of the average liquid crystal director.

4. The liquid crystal display of Claim 1, wherein the compensator further comprises a positively birefringent A-plate compensator layer disposed between the polarizer layer and the analyzer layer, the A-plate layer being oriented with its optic axis relative to the optic axis of the O-plate layer such that retardation of light passing through the compensator at normal incidence is minimized.

5. The liquid crystal display of Claim 1, wherein the compensator further comprises a negatively birefringent C-plate compensator layer disposed between the polarizer layer and the analyzer layer.

6. The liquid crystal display of Claim 1, wherein:
the O-plate layer further comprises a first positively birefringent O-plate compensator layer; and wherein the compensator further comprises:
a second positively birefringent O-plate compensator layer disposed between the polarizer layer and the analyzer layer with its optic axis oriented at a substantially oblique angle with respect to the normal axis and such that the azimuth angles of the first and second O-plate layers are crossed.

7. A liquid crystal display for viewing at various angles with respect to a normal axis perpendicular to the display, comprising:
a polarizer layer having an absorbing axis;
an analyzer layer having an absorbing axis substantially perpendicular to the absorbing axis of the polarizer layer;
a liquid crystal layer disposed between the polarizer layer and the analyzer layer and having a director exhibiting an azimuthal twist through the layer with respect to the normal axis;
a first electrode proximate to a first major surface of the liquid crystal layer;
a second electrode proximate to a second major surface of the liquid crystal layer, the first and second electrodes being adapted to apply a voltage across the liquid crystal layer when the electrodes are connected to a source of electrical potential; and
a compensator, including:
a positively birefringent O-plate compensator layer disposed between the polarizer layer and the analyzer layer with its optic axis oriented at a substantially oblique angle with respect to the normal axis; and
a positively birefringent A-plate compensator layer disposed between the liquid crystal layer and the O-plate layer, the A-plate layer being oriented with its optic axis relative to the optic axis of the O-plate layer such that retardation of light passing through the compensator at normal incidence is minimized.

8. A liquid crystal display for viewing at various angles with respect to a normal axis perpendicular to the display, comprising:
a polarizer layer having an absorbing axis;
an analyzer layer having an absorbing axis substantially perpendicular to the absorbing axis of the polarizer layer;
a liquid crystal layer disposed between the polarizer layer and the analyzer layer and having a director exhibiting an azimuthal twist through the layer with respect to the normal axis;
a first electrode proximate to a first major surface of the liquid crystal layer;
a second electrode proximate to a second major surface of the liquid crystal layer, the first and second electrodes being adapted to apply a voltage across the liquid crystal layer when the electrodes are connected to a source of electrical potential; and
a compensator, including:
a positively birefringent O-plate compensator layer disposed between the polarizer layer and the liquid crystal layer with its optic axis oriented at a substantially oblique angle with respect to the normal axis;

a first positively birefringent A-plate compensator layer disposed between the polarizer layer and the O-plate layer; and

a second positively birefringent A-plate compensator layer disposed between the O-plate layer and the liquid crystal layer, the first and second A-plate layers being oriented with their optic axes relative to the optic axis of the O-plate layer such that retardation of light passing through the compensator at normal incidence is minimized.

9. A liquid crystal display for viewing at various angles with respect to a normal axis perpendicular to the display, comprising:

a polarizer layer having an absorbing axis;

an analyzer layer having an absorbing axis substantially perpendicular to the absorbing axis of the polarizer layer;

a liquid crystal layer disposed between the polarizer layer and the analyzer layer and having a director exhibiting an azimuthal twist through the layer with respect to the normal axis;

a first electrode proximate to a rust major surface of the liquid crystal layer;

a second electrode proximate to a second major surface of the liquid crystal layer, the first and second electrodes being adapted to apply a voltage across the liquid crystal layer when the electrodes are connected to a source of electrical potential; and

a compensator, including:

a positively birefringent O-plate compensator layer disposed between the polarizer layer and the liquid crystal layer with its optic axis oriented at a substantially oblique angle with respect to the normal axis;

a first positively birefringent A-plate compensator layer disposed between the O-plate layer and the liquid crystal layer; and

a second positively birefringent A-plate compensator layer disposed between the liquid crystal layer and the analyzer layer, the first and second A-plate layers being oriented with their optic axes relative to the optic axis of the O-plate layer such that retardation of light passing through the compensator at normal incidence is minimized.

10. A liquid crystal display for viewing at various angles with respect to a normal axis perpendicular to the display, comprising:

a polarizer layer having an absorbing axis;

an analyzer layer having an absorbing axis substantially perpendicular to the absorbing axis of the polarizer layer;

a liquid crystal layer disposed between the polarizer layer and the analyzer layer and having a director exhibiting an azimuthal twist through the layer with respect to the normal axis;

a first electrode proximate to a first major surface of the liquid crystal layer;

a second electrode proximate to a second major surface of the liquid crystal layer, the first and second electrodes being adapted to apply a voltage across the liquid crystal layer when the electrodes are connected to a source of electrical potential; and

a compensator, including:

a positively birefringent O-plate compensator layer disposed between the polarizer layer and the liquid crystal layer with its optic axis oriented at a substantially oblique angle with respect to the normal axis;

a positively birefringent A-plate compensator layer disposed between the O-plate layer and the liquid crystal layer, the A-plate layer being oriented with its optic axis relative to the optic axis of the O-plate layer such that retardation of light passing through the compensator at normal incidence is minimized; and

a negatively birefringent C-plate compensator layer disposed between the A-plate layer and the liquid crystal layer.

11. A liquid crystal display for viewing at various angles with respect to a normal axis perpendicular to the display, comprising:

a polarizer layer having an absorbing axis;

an analyzer layer having an absorbing axis substantially perpendicular to the absorbing axis of the polarizer layer;

a liquid crystal layer disposed between the polarizer layer and the analyzer layer and having a director exhibiting an azimuthal twist through the layer with respect to the normal axis;

a first electrode proximate to a first major surface of the liquid crystal layer;

a second electrode proximate to a second major surface of the liquid crystal layer, the first and second electrodes being adapted to apply a voltage across the liquid crystal layer when the electrodes are connected to a source of electrical potential; and

a compensator, including:

a first positively birefringent O-plate compensator layer disposed between the polarizer layer and the liquid crystal layer with its optic axis oriented at a substantially oblique angle with respect to the normal axis;

a second positively birefringent O-plate compensator layer disposed between the first O-plate layer and the liquid crystal layer, with its optical axis oriented at a substantially oblique angle with respect to the normal axis and such that the azimuth angles of the first and second O-plate layers are crossed;

a first positively birefringent A-plate compensator layer disposed between the polarizer layer and the first O-plate layer; and

a second positively birefringent A-plate compensator layer disposed between the second O-plate layer and the liquid crystal layer, the first and second A-plate layers being oriented with their optic axes relative to the optic axis of the O-plate compensator layer such that retardation of light passing through the compensator at normal incidence is minimized.

12. A liquid crystal display for viewing at various angles with respect to a normal axis perpendicular to the display, comprising:

a polarizer layer having an absorbing axis;

an analyzer layer having an absorbing axis substantially perpendicular to the absorbing axis of the polarizer layer;

a liquid crystal layer disposed between the polarizer layer and the analyzer layer and having a director exhibiting an azimuthal twist through the layer with respect to the normal axis;

a first electrode proximate to a first major surface of the liquid crystal layer;

a second electrode proximate to a second major surface of the liquid crystal layer, the first and second electrodes being adapted to apply a voltage across the liquid crystal layer when the electrodes are connected to a source of electrical potential; and

a compensator, including:

a first positively birefringent O-plate compensator layer disposed between the polarizer layer and the liquid crystal layer with its optic axis oriented at a substantially oblique angle with respect to the normal axis;

a second positively birefringent O-plate compensator layer disposed between the liquid crystal layer and the analyzer layer with its optic axis oriented at a substantially oblique angle with respect to the normal axis;

a positively birefringent A-plate compensator layer disposed between the polarizer layer and the first O-plate layer, the A-plate layer being oriented with its optic axis relative to the optic axis of the first O-plate layer such that retardation of light passing through the compensator at normal incidence is minimized; and

a first negatively birefringent C-plate compensator layer disposed between the first O-plate layer and the liquid crystal layer; and

a second negatively birefringent C-plate compensator layer disposed between the liquid crystal layer and the second O-plate layer.

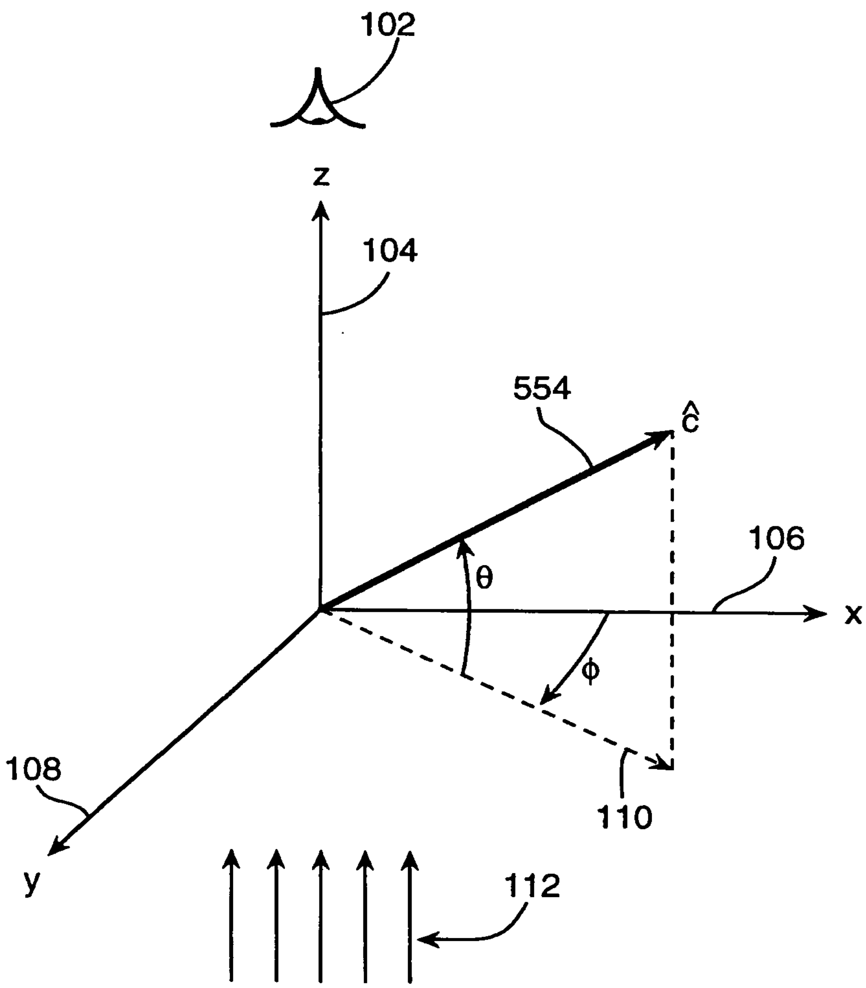

FIGURE 1

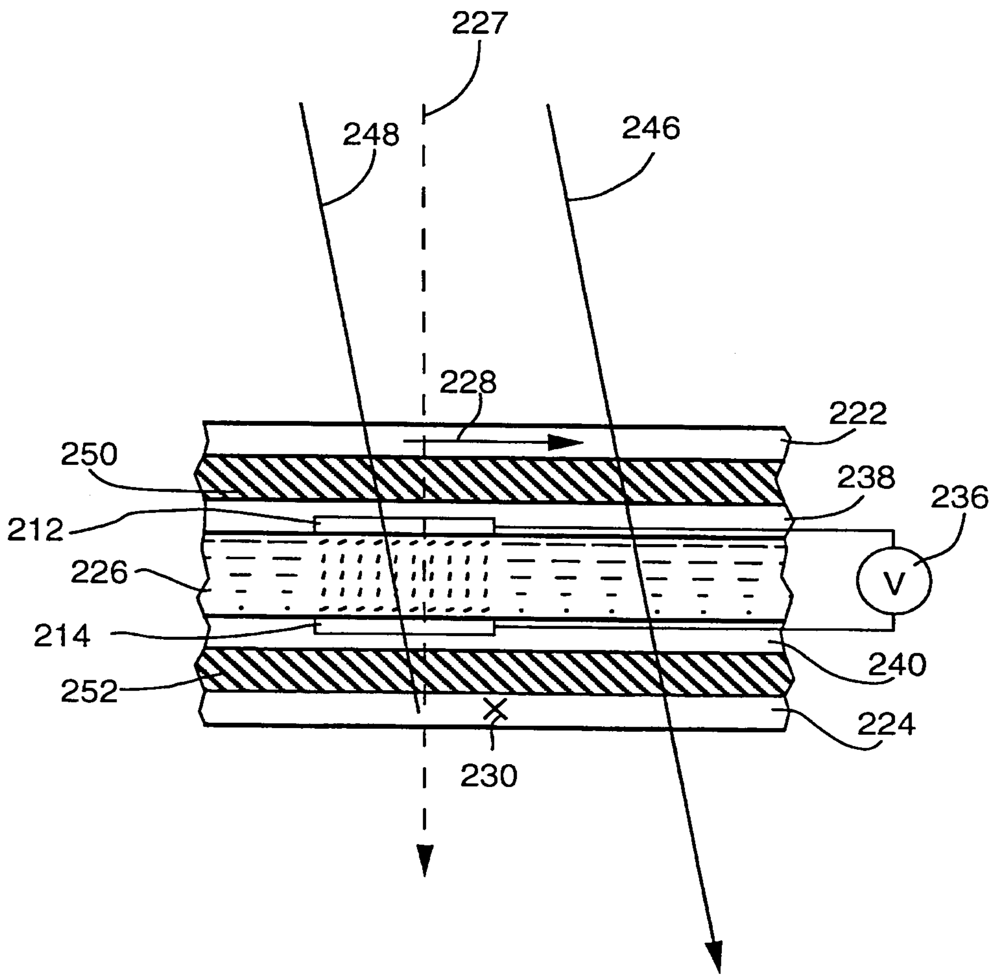

FIGURE 2

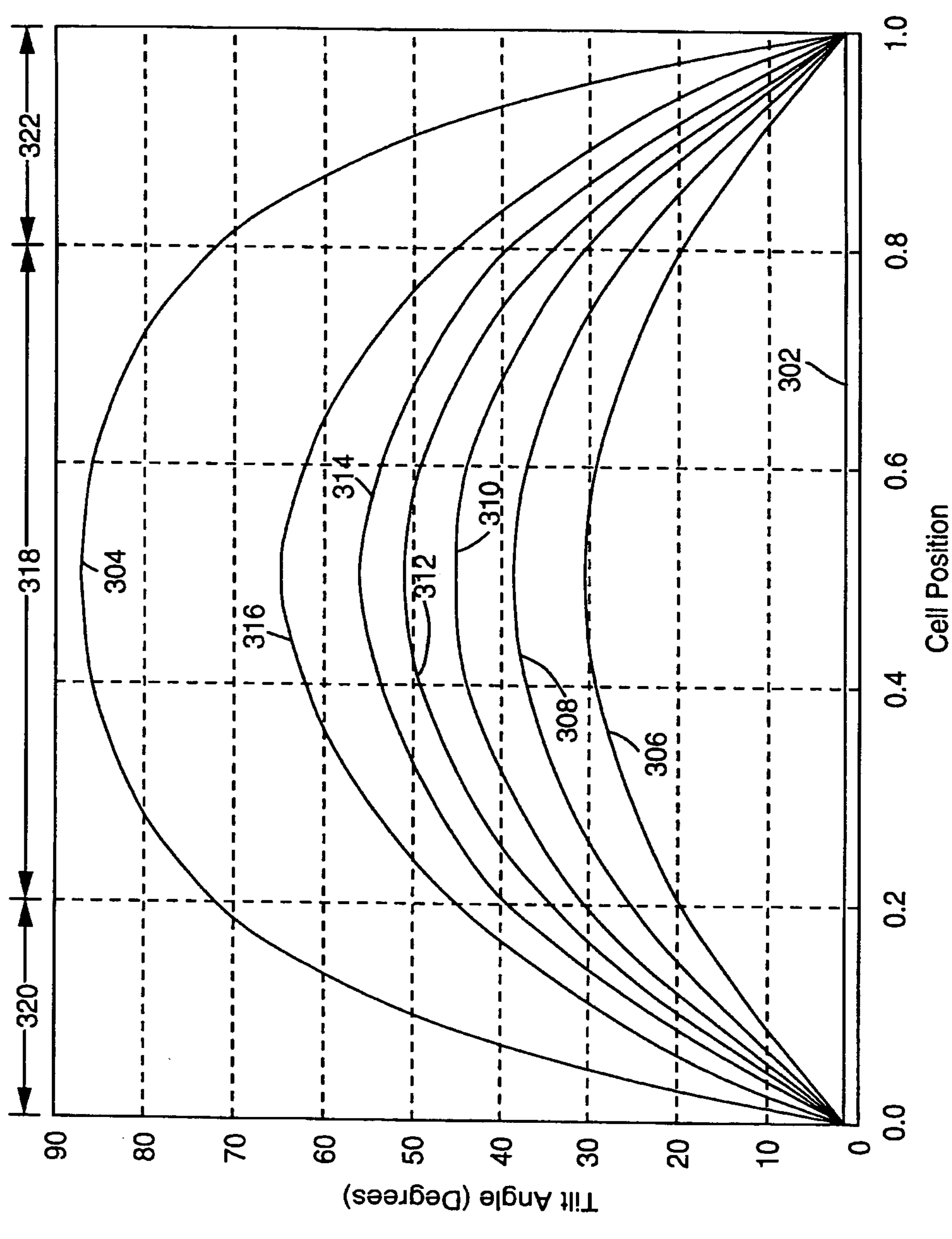
Tilt Angle (Degrees)
0
10
20
30
40
50
60
70
80
90
Cell Position
0.0
0.2
0.4
0.6
0.8
1.0
302
304
306
308
310
312
314
316
318
320
322

FIGURE 3

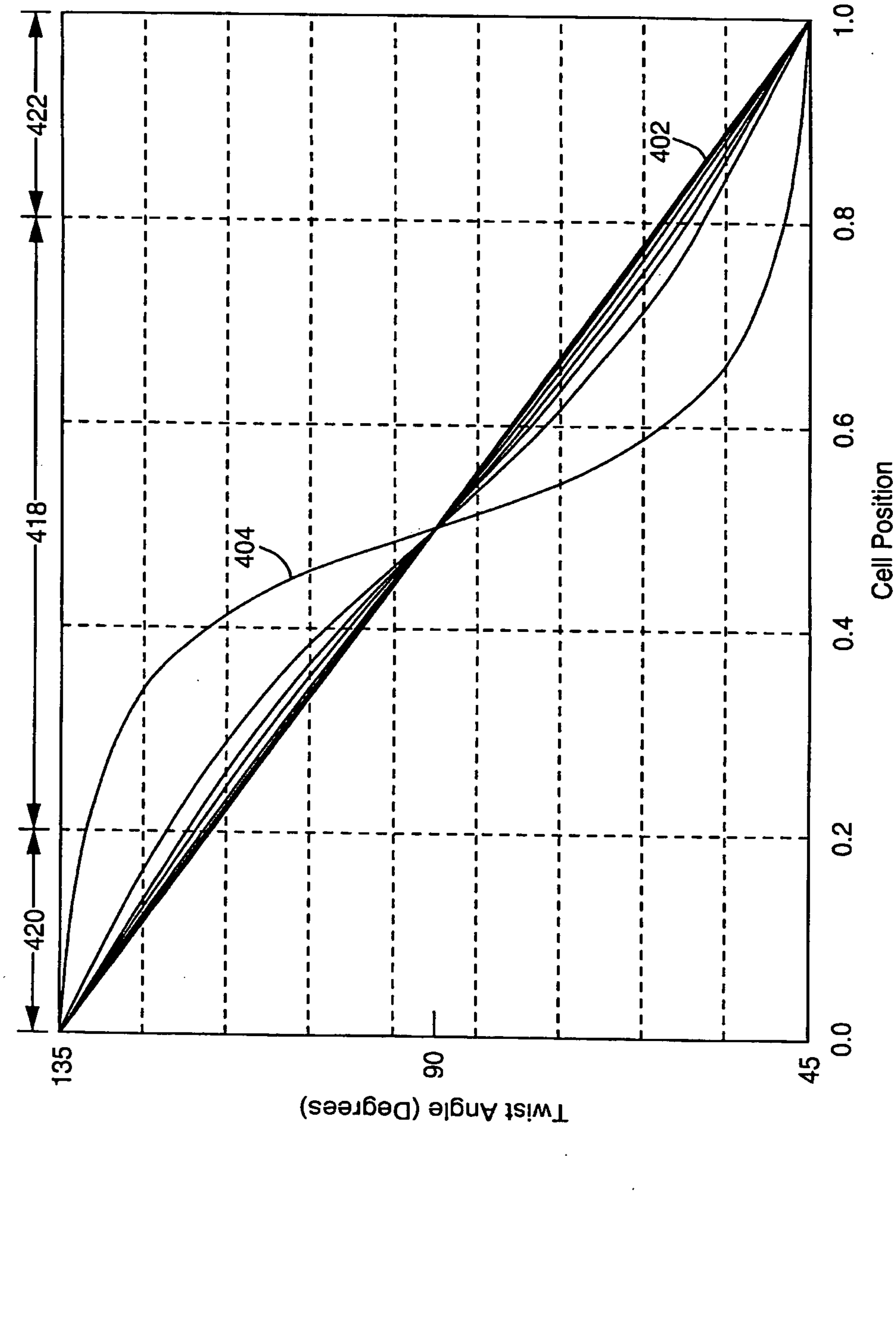
420
418
422
404
402
135
90
45
Twist Angle (Degrees)
0.0
0.2
0.4
0.6
0.8
1.0
Cell Position

FIGURE 4

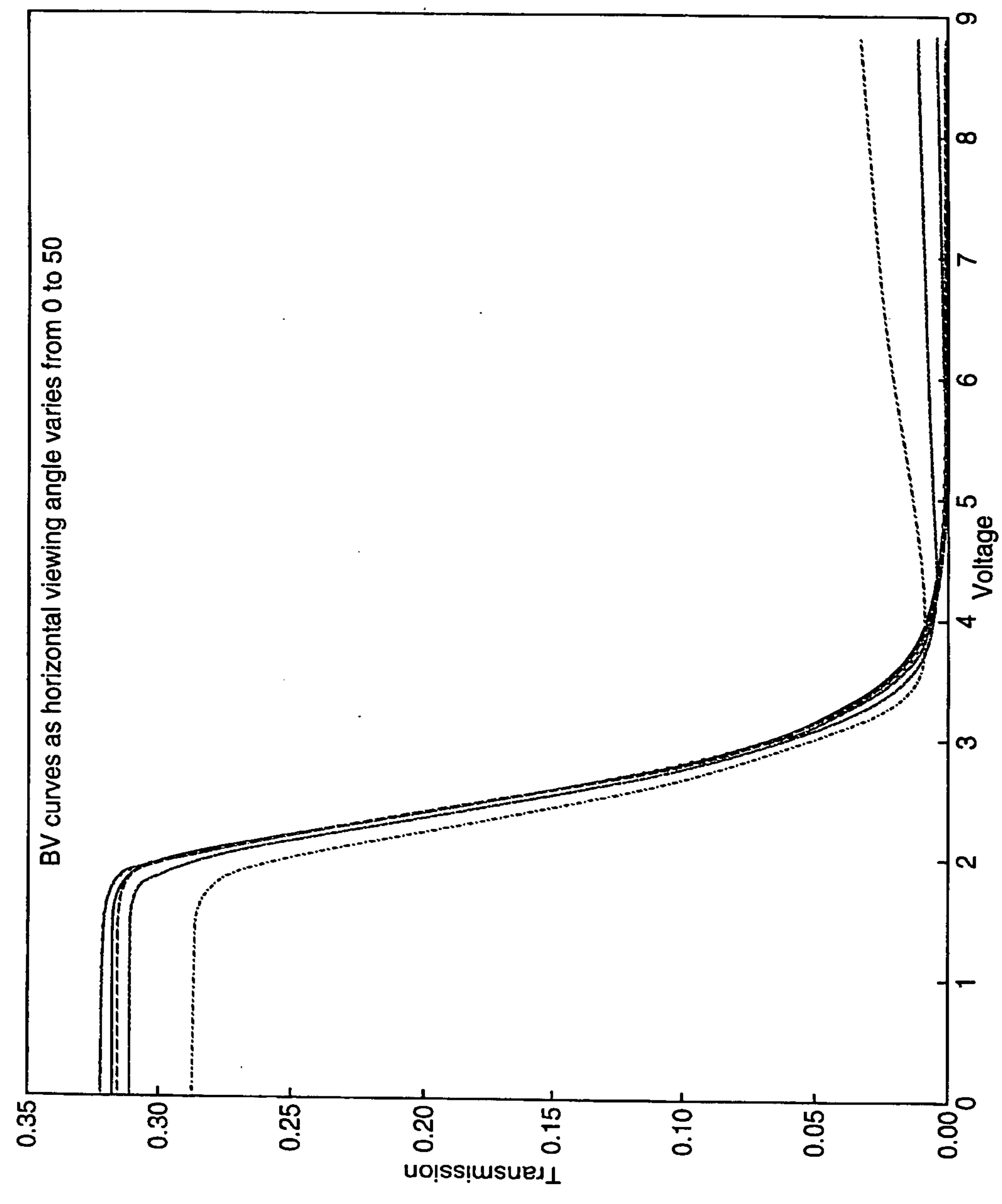
BV curves as horizontal viewing angle varies from 0 to 50
Transmission
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Voltage
0
1
2
3
4
5
6
7
8
9

FIGURE 5

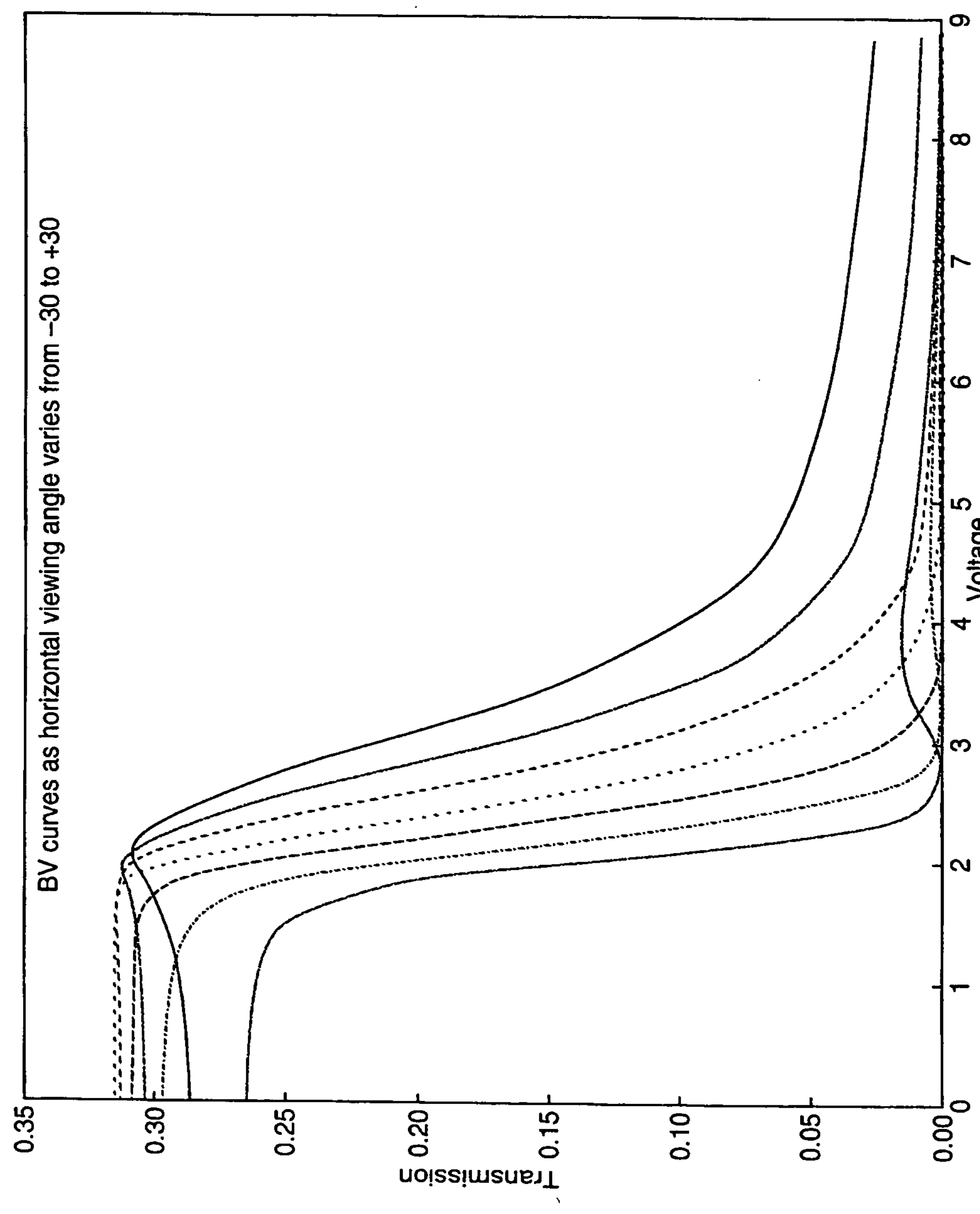
BV curves as horizontal viewing angle varies from −30 to +30
Transmission
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Voltage
0
1
2
3
4
5
6
7
8
9

FIGURE 6

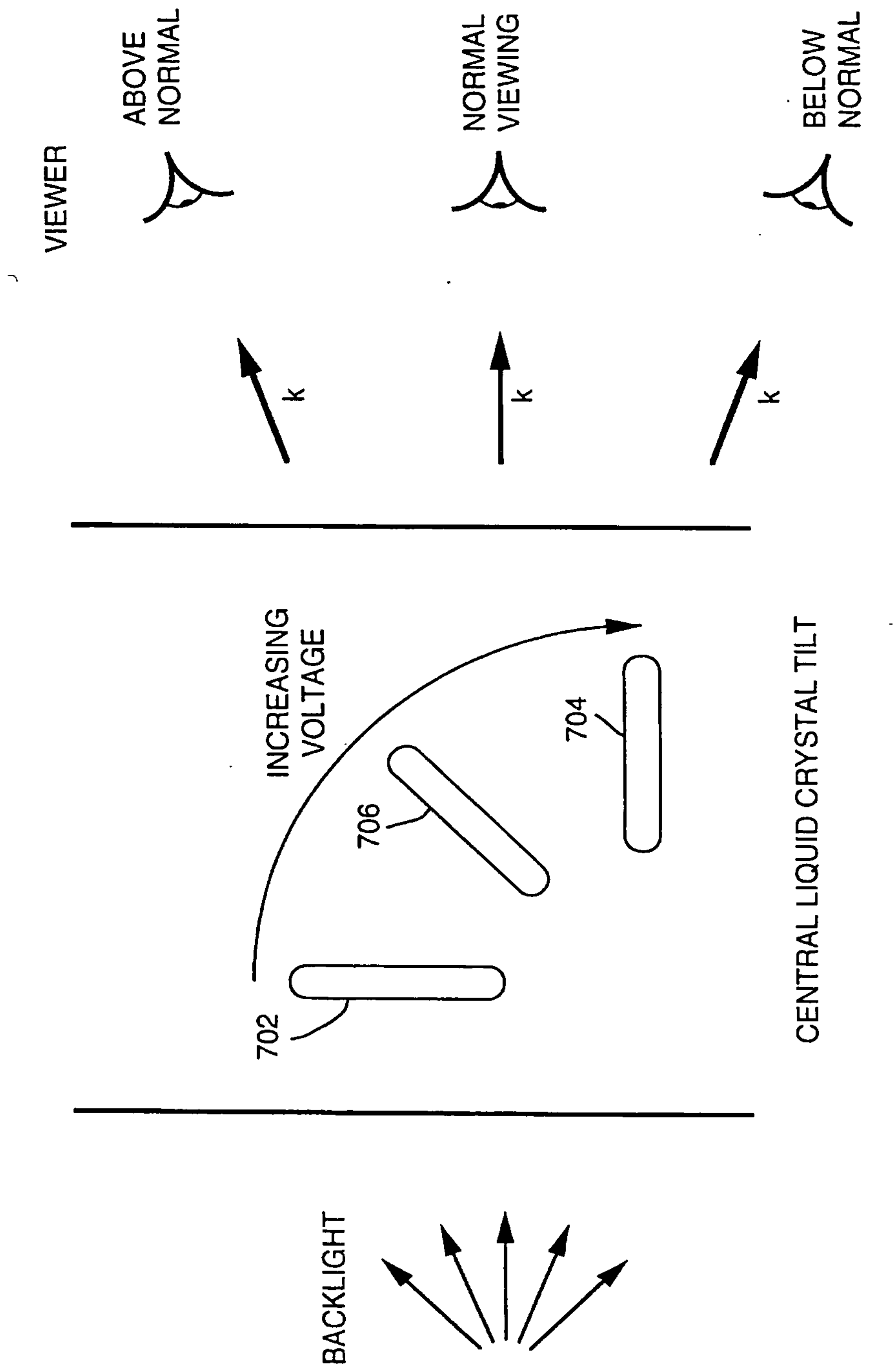
VIEWER
ABOVE NORMAL
NORMAL VIEWING
BELOW NORMAL
k
k
k
INCREASING VOLTAGE
702
706
704
CENTRAL LIQUID CRYSTAL TILT
BACKLIGHT

FIGURE 7

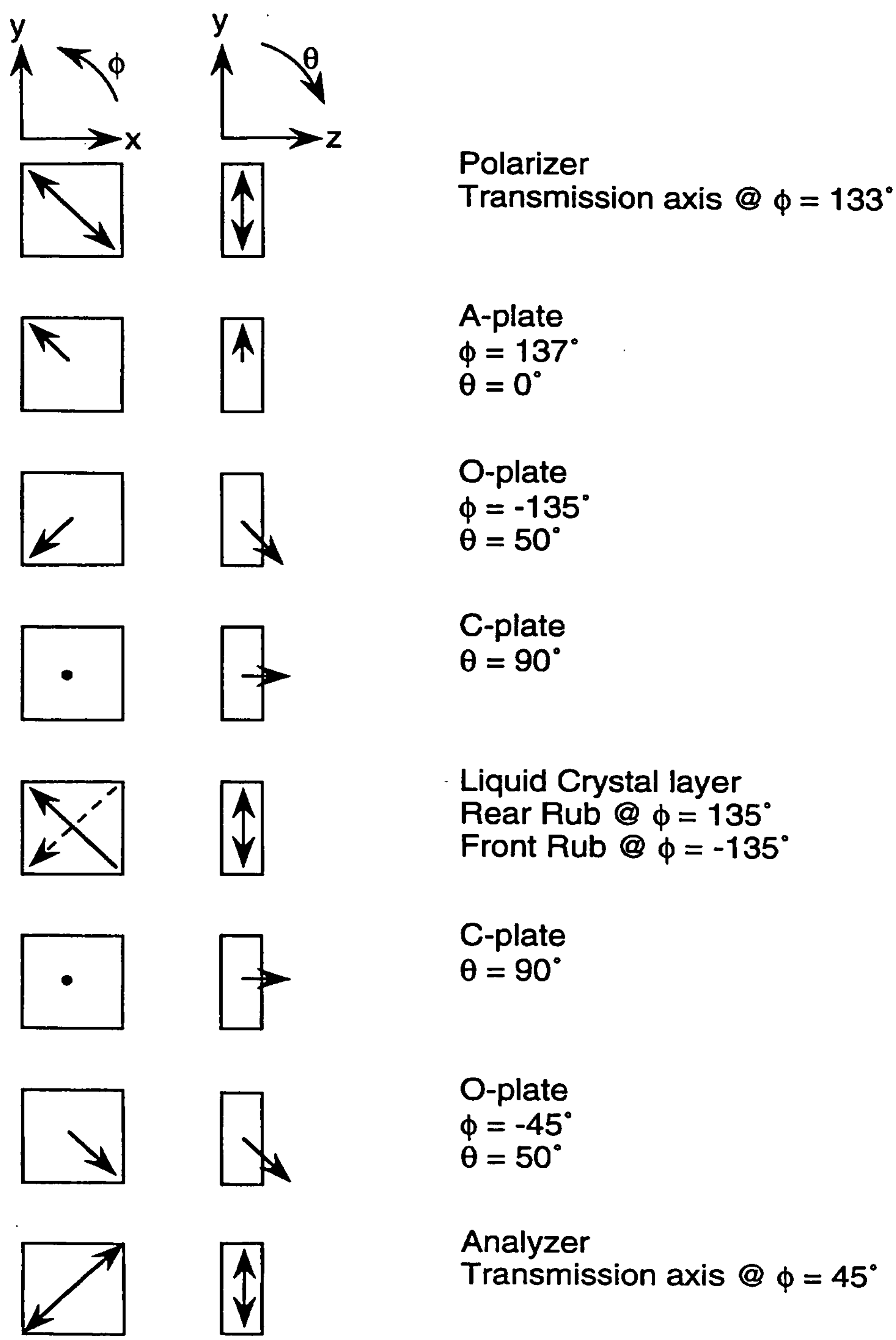
y
φ
x
y
θ
z
Polarizer
Transmission axis @ φ = 133°
A-plate
φ = 137°
θ = 0°
O-plate
φ = -135°
θ = 50°
C-plate
θ = 90°
Liquid Crystal layer
Rear Rub @ φ = 135°
Front Rub @ φ = -135°
C-plate
θ = 90°
O-plate
φ = -45°
θ = 50°
Analyzer
Transmission axis @ φ = 45°

FIGURE 8

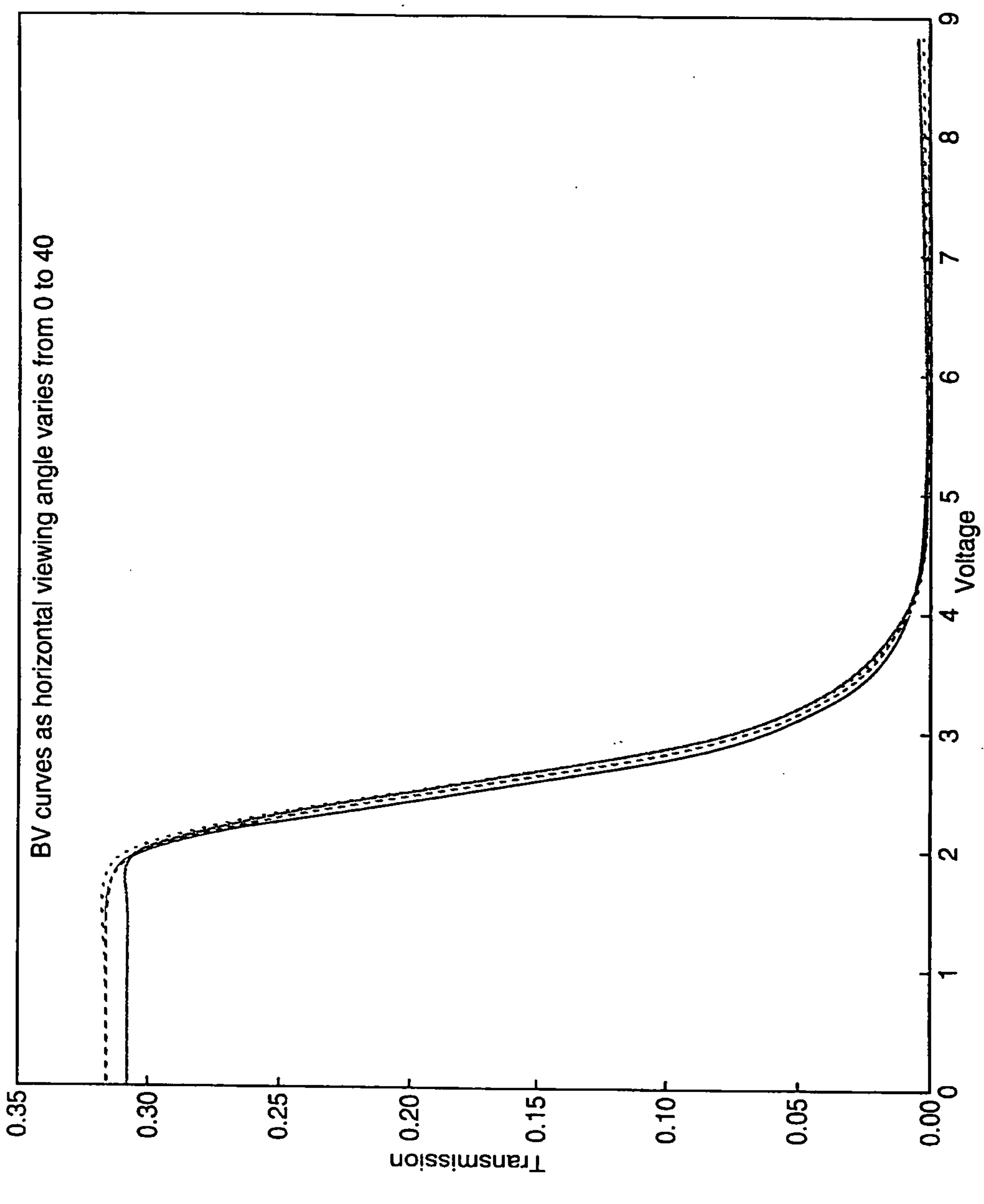
BV curves as horizontal viewing angle varies from 0 to 40
Transmission
Voltage
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0
1
2
3
4
5
6
7
8
9

FIGURE 9

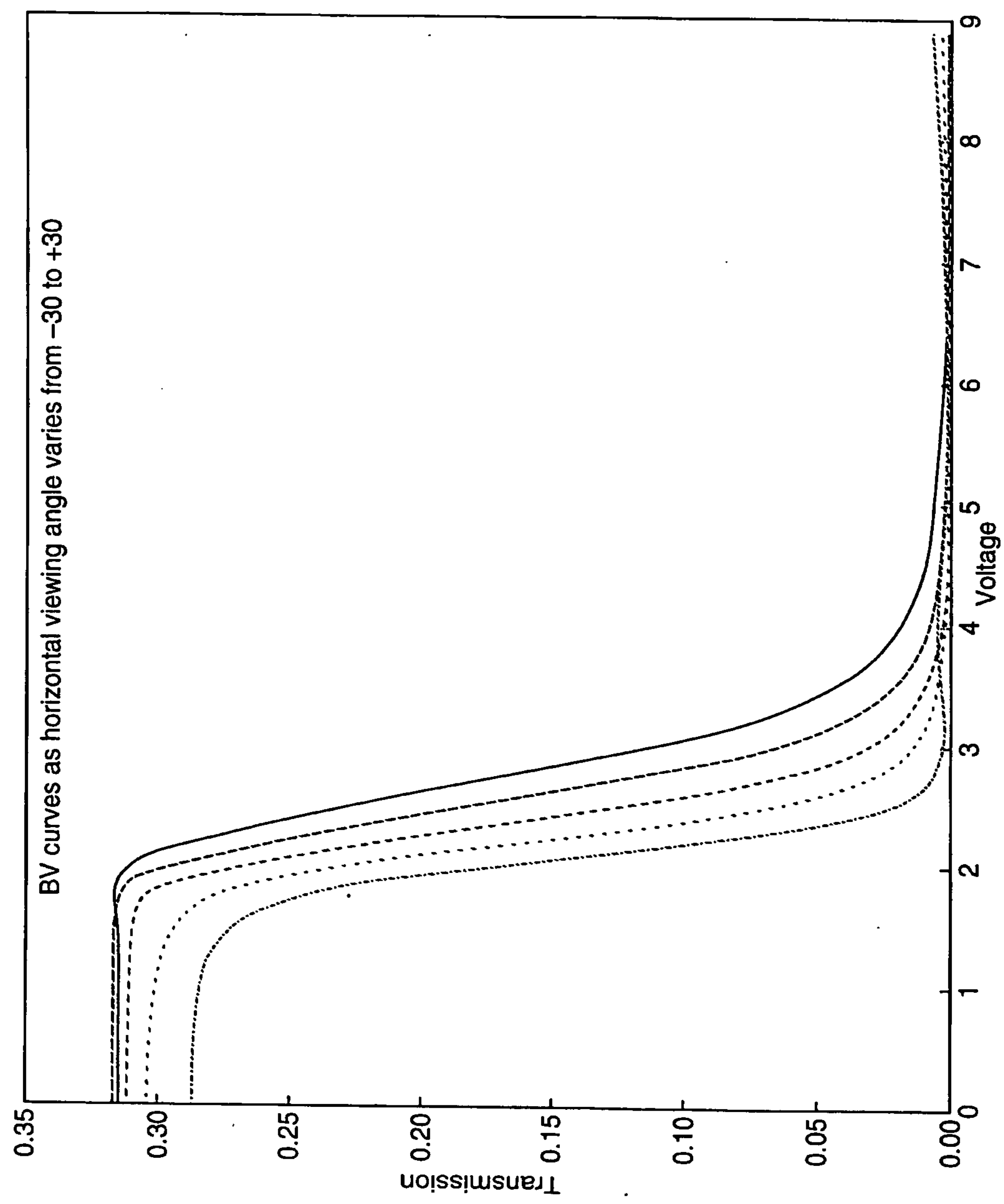
BV curves as horizontal viewing angle varies from −30 to +30
Transmission
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Voltage
0
1
2
3
4
5
6
7
8
9

FIGURE 10

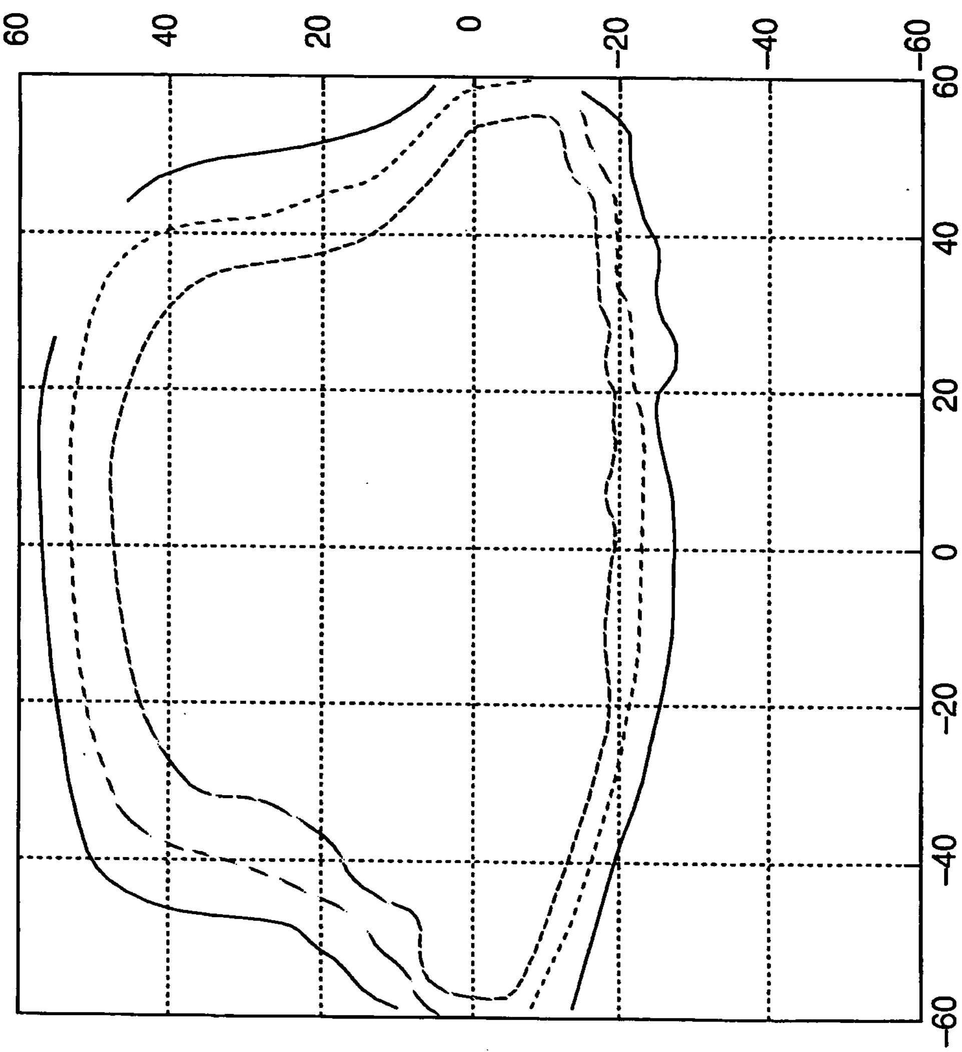

FIGURE 11

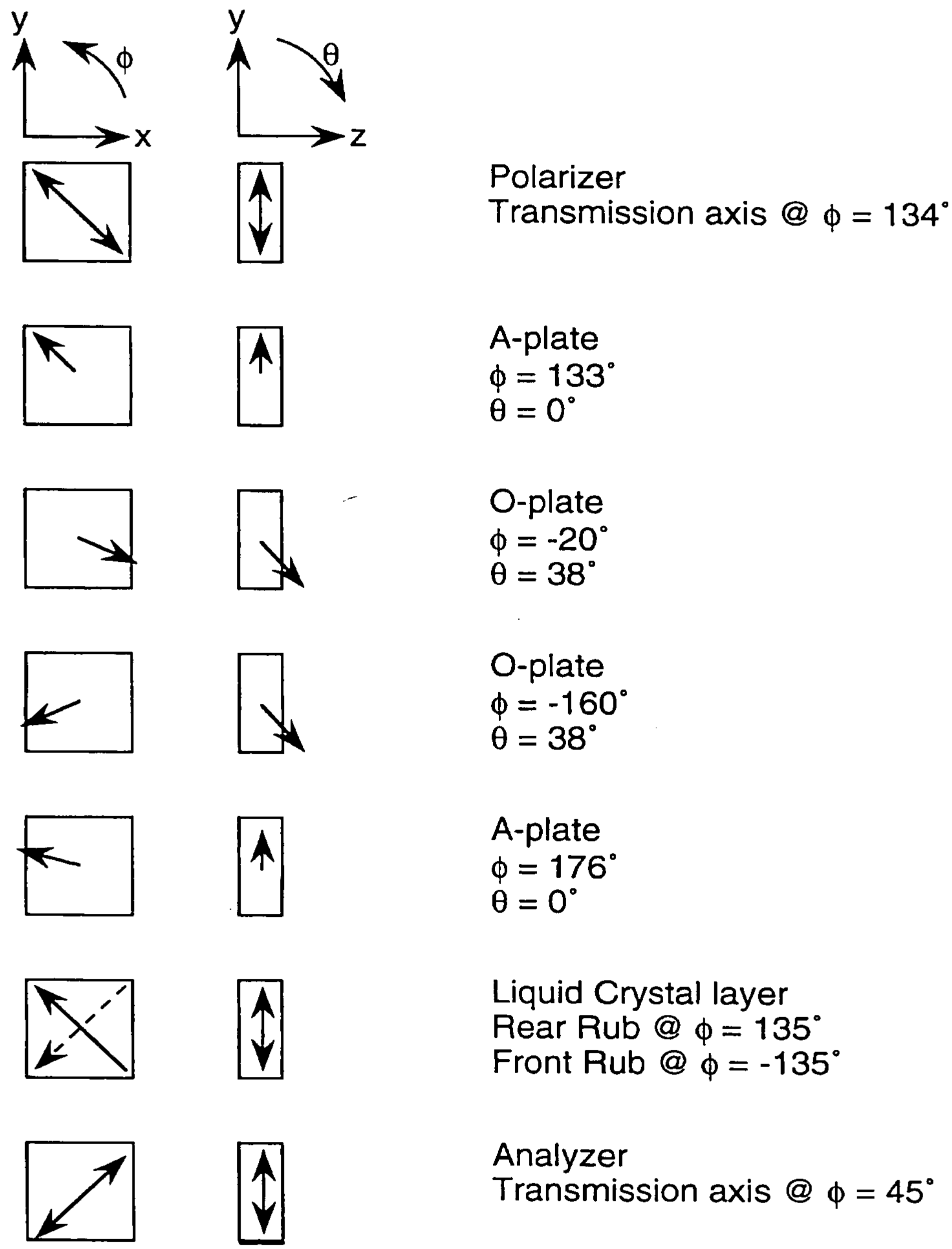
y
φ
x
y
θ
z
Polarizer
Transmission axis @ φ = 134°
A-plate
φ = 133°
θ = 0°
O-plate
φ = -20°
θ = 38°
O-plate
φ = -160°
θ = 38°
A-plate
φ = 176°
θ = 0°
Liquid Crystal layer
Rear Rub @ φ = 135°
Front Rub @ φ = -135°
Analyzer
Transmission axis @ φ = 45°

FIGURE 12

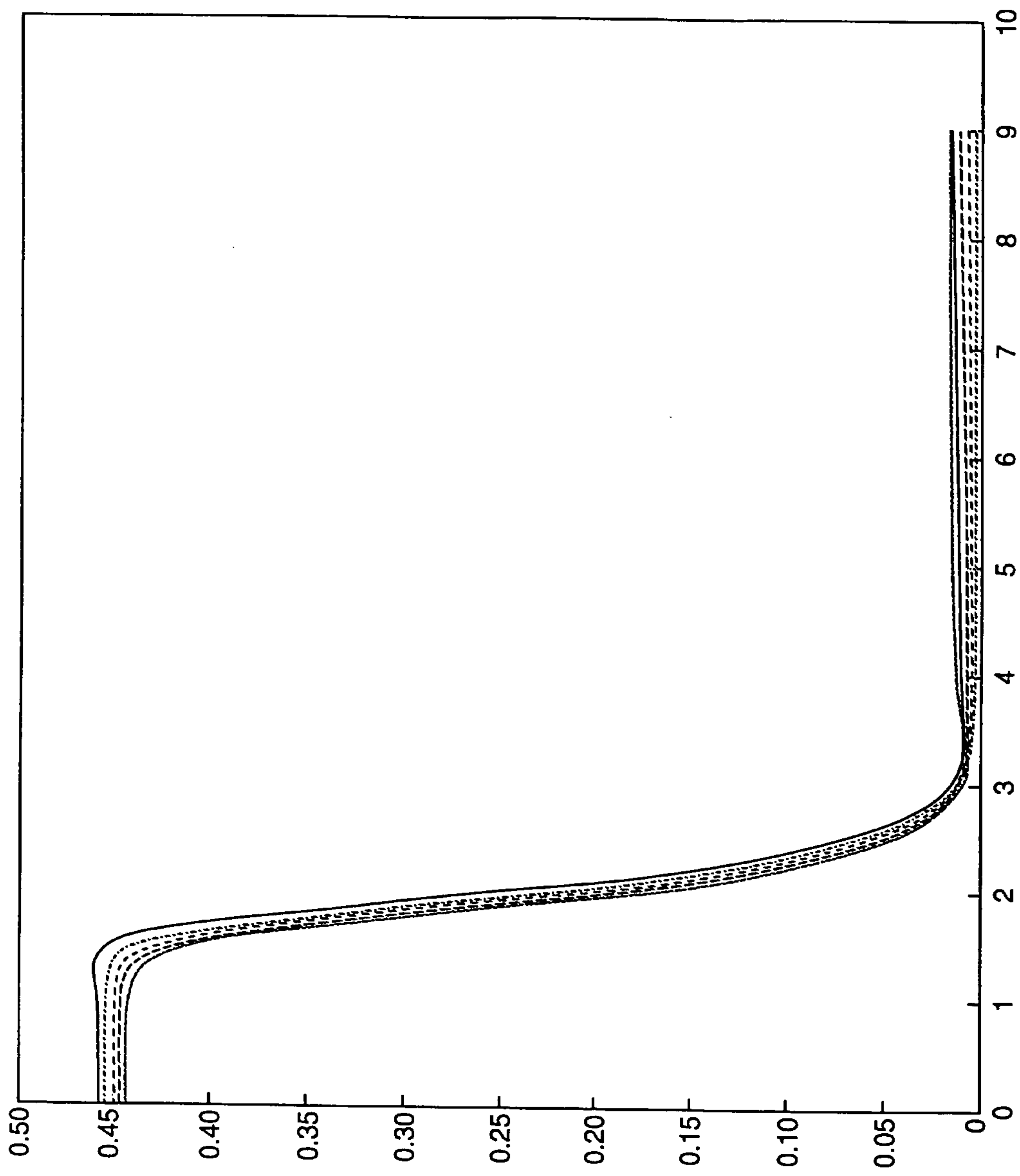

FIGURE 13

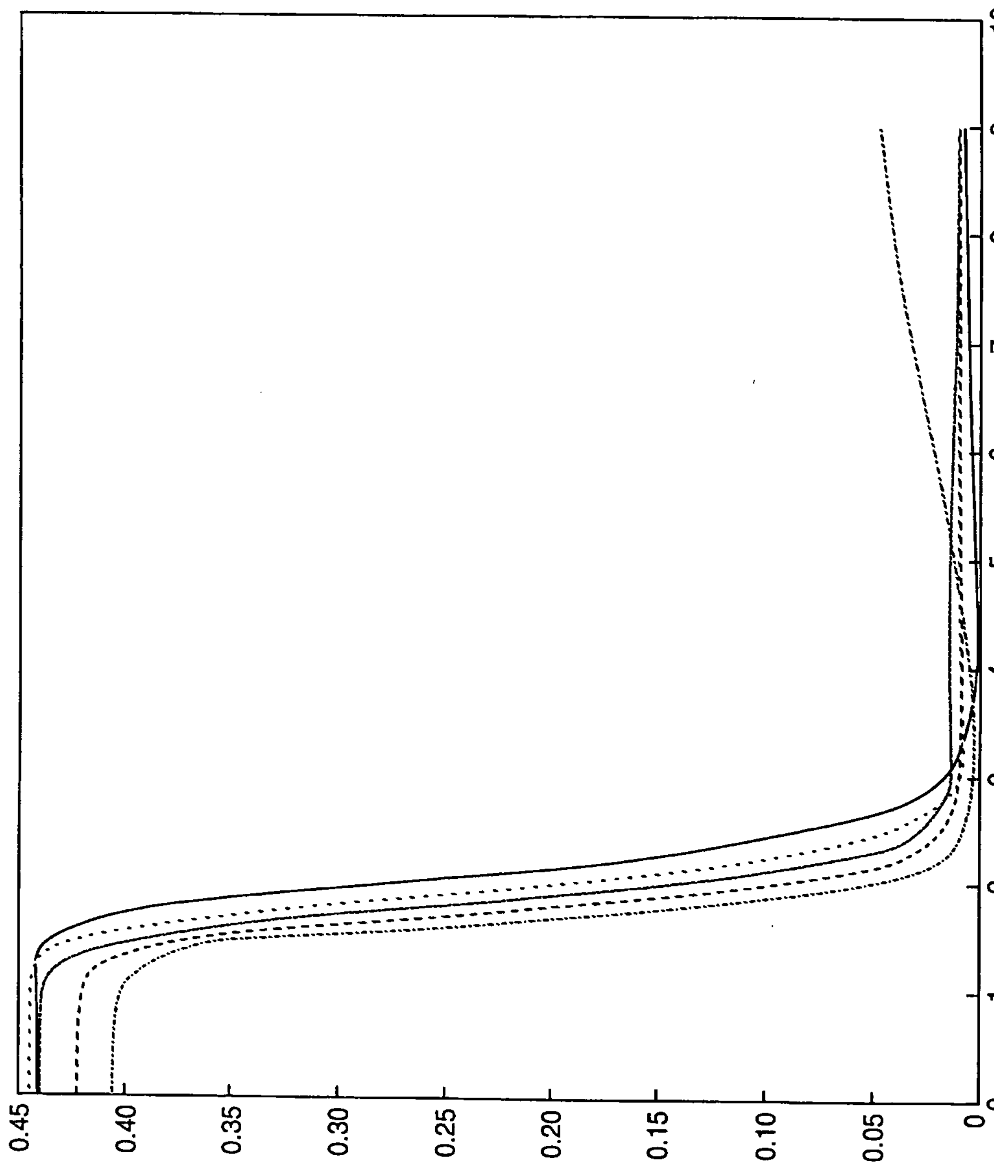

FIGURE 14

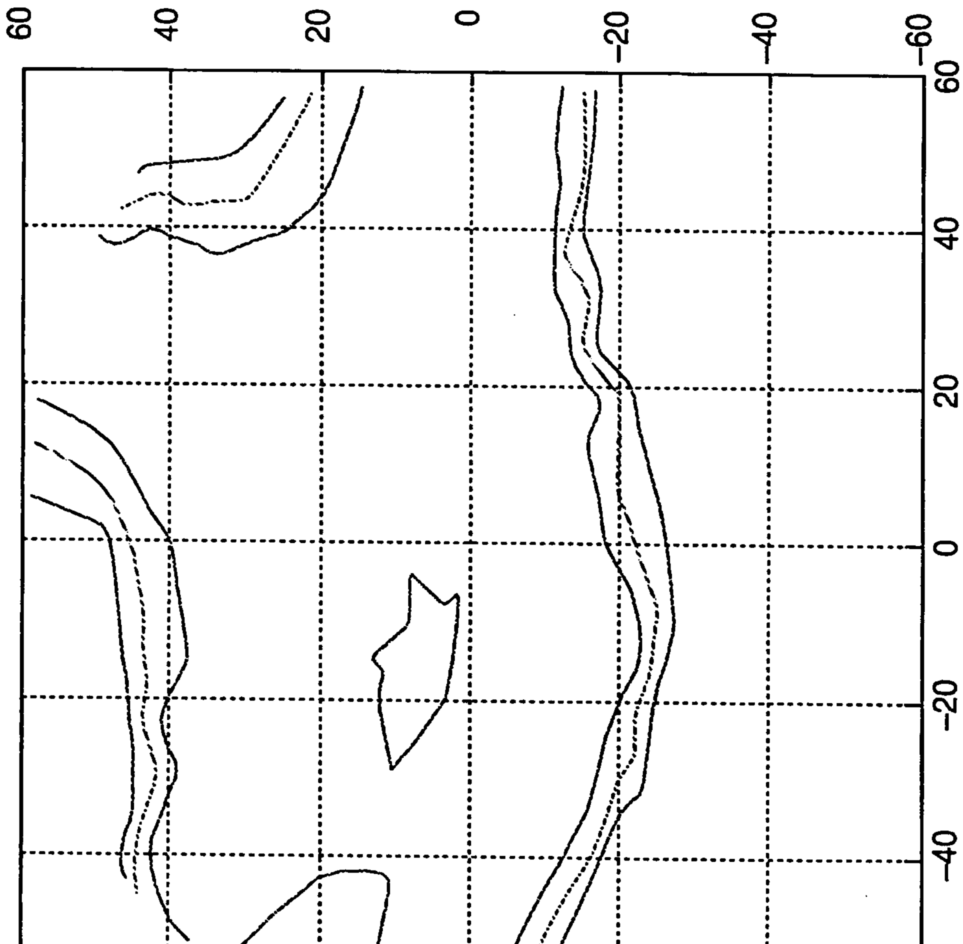

FIGURE 15

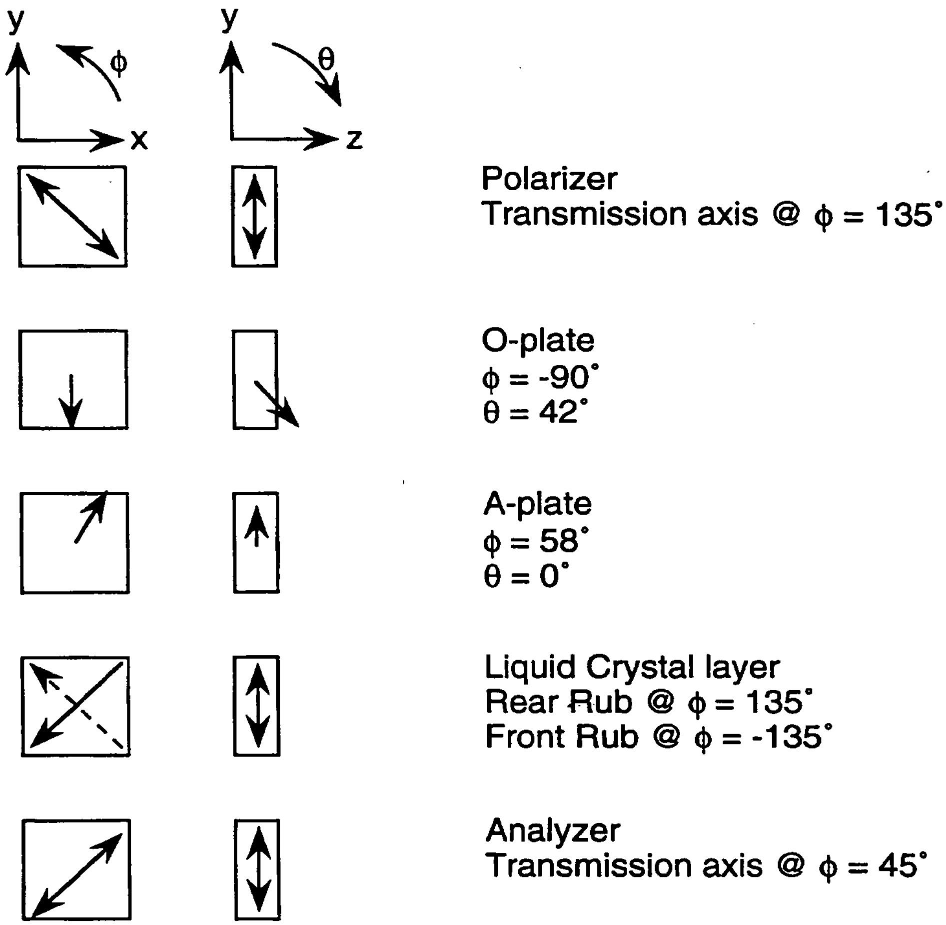
y
φ
x
y
θ
z
Polarizer
Transmission axis @ φ = 135°
O-plate
φ = -90°
θ = 42°
A-plate
φ = 58°
θ = 0°
Liquid Crystal layer
Rear Rub @ φ = 135°
Front Rub @ φ = -135°
Analyzer
Transmission axis @ φ = 45°

FIGURE 16

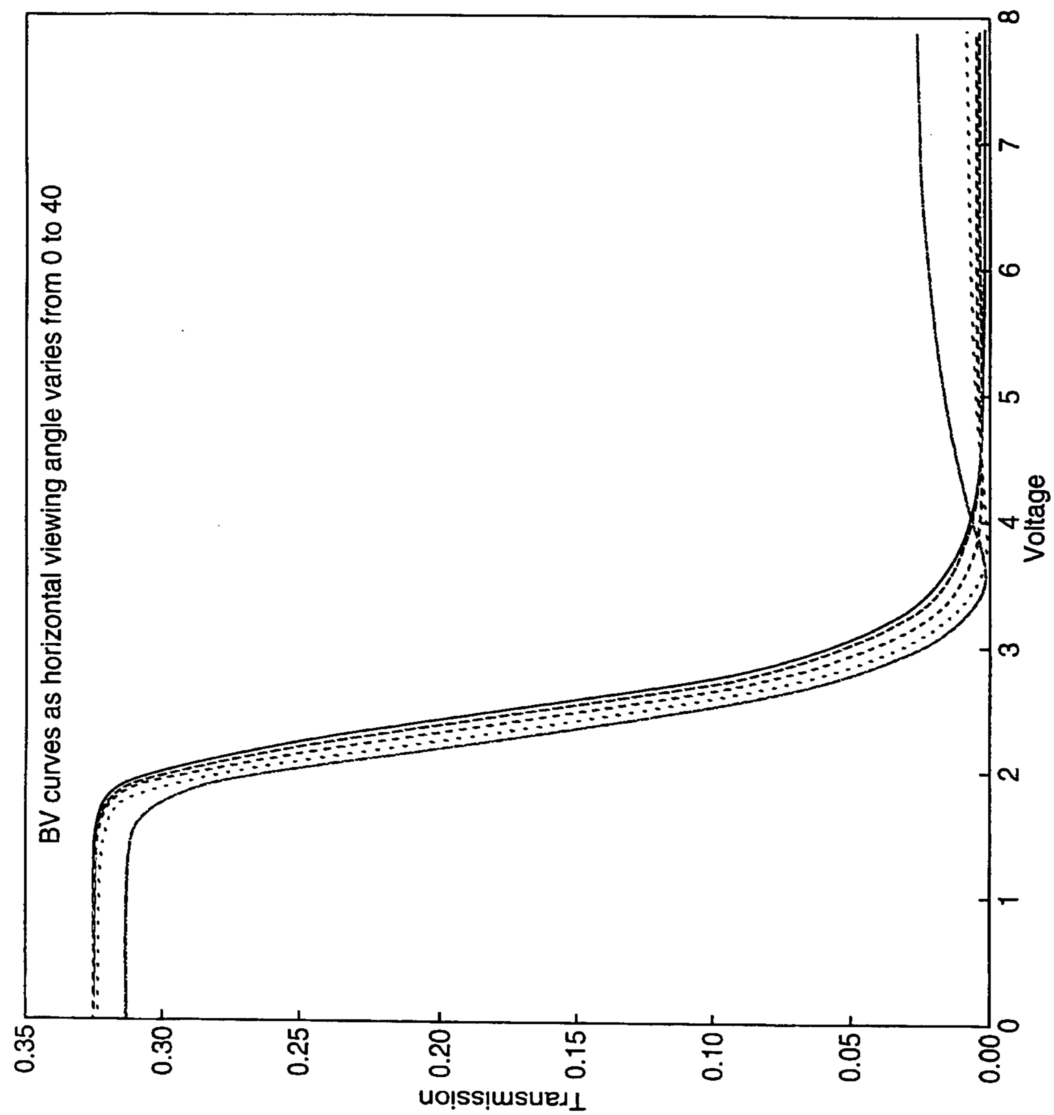
BV curves as horizontal viewing angle varies from 0 to 40
Transmission
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
1
2
3
4
5
6
7
8
Voltage

FIGURE 17

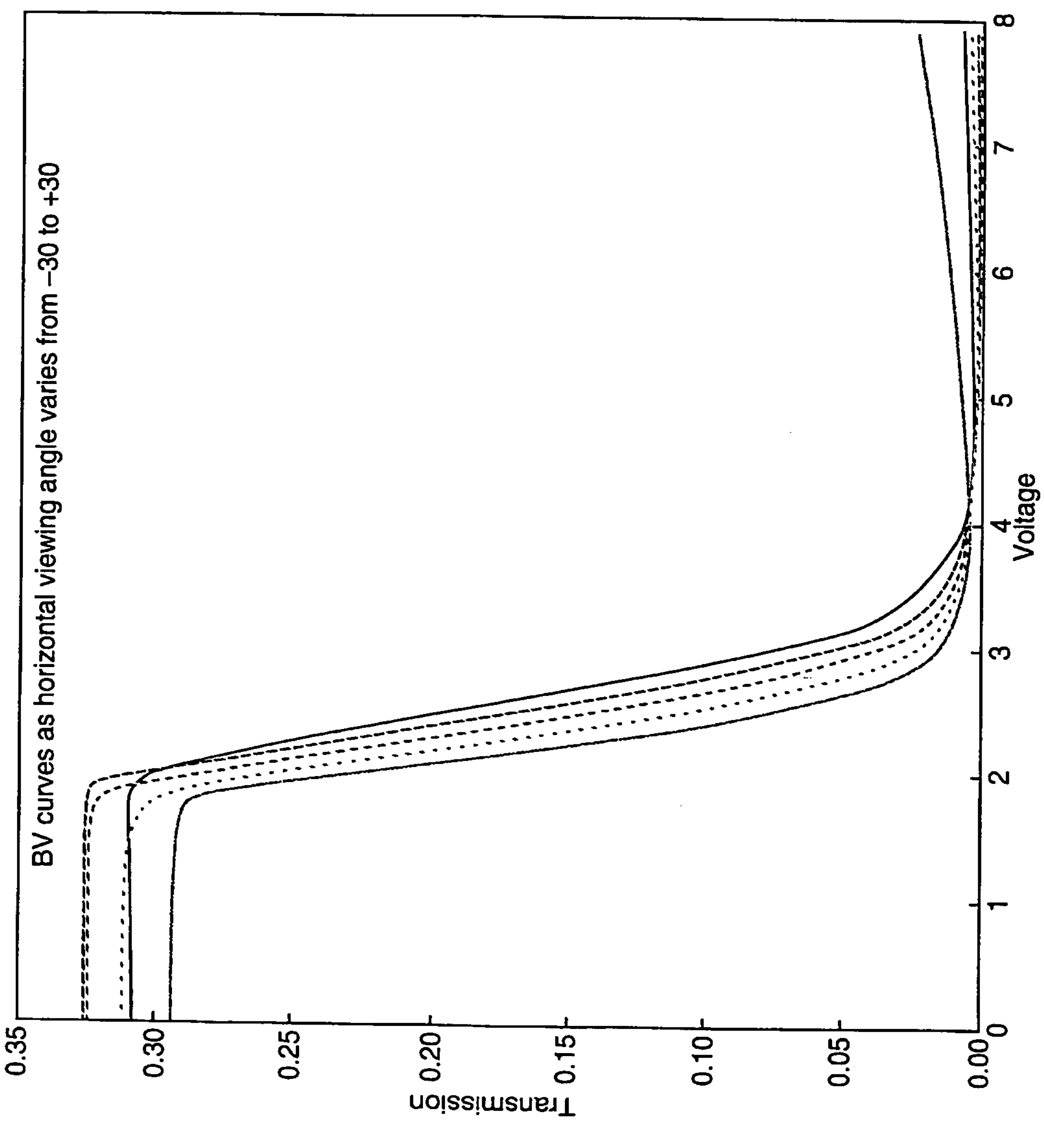
BV curves as horizontal viewing angle varies from −30 to +30
Transmission
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Voltage
0
1
2
3
4
5
6
7
8

FIGURE 18

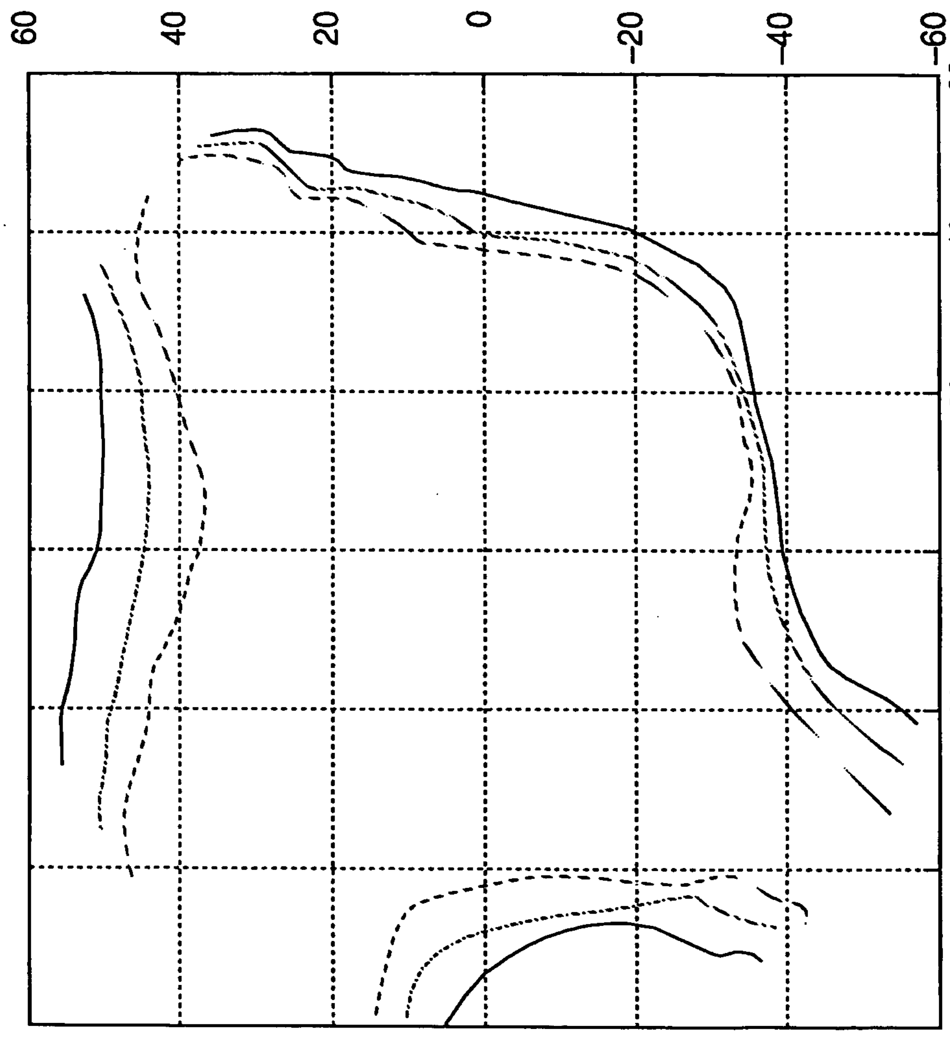

FIGURE 19

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 95 10 5034

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	EP-A-0 576 342 (THOMSON) * page 3, line 41 - page 4, line 19; figures 5,6 *	1	G02F1/1335 G02B5/30
X	IBM TECHNICAL DISCLOSURE BULLETIN, vol. 33, no. 12, NEW YORK US, pages 201-202, XP 000121640 'Multicolor Parallel-oriented Nematic Liquid Crystal Displays using Optical Compensation Films'	1	
A	* page 201 *	2	
X	US-A-5 184 237 (IIMURA)	1	
A	* claims 1,5,10; example 3 *	6,11,12	
A	EP-A-0 367 288 (FUJI) * page 3, line 40 - page 4, line 17 * * page 5, paragraph 4 *	1,4,5, 7-9	
A	EP-A-0 576 931 (CASIO) * column 5, line 3 - line 28; example 1 *	1	TECHNICAL FIELDS SEARCHED (Int.Cl.6)
A	PATENT ABSTRACTS OF JAPAN vol. 13 no. 540 (P-969) [3888] ,5 December 1989 & JP-A-01 222220 (MATSUSHITA) * abstract *	1	G02F G02B
A	EP-A-0 576 304 (SHARP) * page 11, line 20 - line 24 *	1	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	6 July 1995	Wongel, H

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 864 906 A1

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(43) Date of publication:
16.09.1998 Bulletin 1998/38

(51) Int. Cl.^{6}: G02F 1/1335, G02B 5/30, G02F 1/139

(21) Application number: 98104264.1

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AT BE CH DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE
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(30) Priority: 10.03.1997 JP 55316/97

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(54) Liquid crystal display and optical compensatory sheet

(57) A liquid crystal display comprises a liquid crystal cell of a vertical alignment mode, one or two optical compensatory sheets arranged on one or both sides of the liquid crystal cell and two polarizing elements arranged on the optical compensatory sheets or the liquid crystal cell. The liquid crystal cell contains a liquid crystal molecule. The liquid crystal molecule is essentially vertically aligned while not applying voltage to the cell, and is essentially horizontally aligned while applying voltage to the cell. The optical compensatory sheet comprises a transparent substrate and an optically anisotropic layer. The optically anisotropic layer contains a discotic compound. The optically anisotropic layer has an optical anisotropy to optically compensate an optical anisotropy of the liquid crystal cell while applying voltage to the cell. The optical compensatory sheet has a retardation value in plane in the range of -10 to 10 nm.

EP 0 864 906 A1

Description

FIELD OF THE INVENTION

The present invention relates to a liquid crystal display using a liquid crystal cell of a vertical alignment (VA) mode, in which a liquid crystal molecule is essentially vertically aligned while not applying voltage to the cell, and is essentially horizontally aligned while applying voltage to the cell.

BACKGROUND OF THE INVENTION

A liquid crystal display (LCD) has advantages of thin shape, light weight and low consumption of electric power, compared with a cathode ray tube (CRT). Most of the commercially available liquid crystal displays usually use a twisted nematic liquid crystal. A liquid crystal display mode is classified into a birefringent mode and an optical rotatory mode.

In a liquid crystal display of a birefringent mode, alignment of liquid crystal molecules is twisted over 90°. The transmittance of the supper twisted nematic (STN) liquid crystal display is changed abruptly over a threshold voltage when applying voltage to the cell. Accordingly, the liquid crystal display of the birefringent mode can display a large image by a time-sharing addressing method, even though an electrode consists of a simple matrix without an active matrix (such as a thin layer transistor or diode). However, the liquid crystal display using the supper twisted liquid crystal molecule has a slow response speed (several hundreds milliseconds). Further, it is difficult for the simple matrix to display a gray scale image.

A liquid crystal display having an active matrix (e.g., TFT-LCD, MIM-LCD) uses a liquid crystal molecule twisted at 90° of an optical rotatory mode. The twisted nematic liquid crystal display (TN-LCD) has a fast response speed (several ten milliseconds). Further, the TN-LCD can display an image of high contrast. Therefore, the TN-LCD is predominant over commercially available liquid crystal displays.

Color and contrast in an image displayed in a conventional liquid crystal display depend on the viewing angle. A liquid crystal display is inferior to CRT in the viewing angle dependence.

An optical compensatory sheet is used to remove color formed in a liquid crystal cell. An optical compensatory sheet of a specific optical characteristic has another function of enlarging a viewing angle of a liquid crystal display.

A stretched birefringent film has been used as the optical compensatory sheet. Japanese Patent Provisional Publication No. 6(1994)-75116 and European Patent No. 576, 304A1 disclose an optically negative uniaxial compensatory sheet (a stretched birefringent film) having an inclined optic axis. The optical compensatory sheet has the function of enlarging a viewing angle.

It has been proposed to use an optical compensatory sheet comprising a transparent substrate and an optically anisotropic layer in place of the stretched birefringent film. The optically anisotropic layer is usually formed by aligning discotic compounds and fixing the aligned compounds. The discotic compounds usually have a large birefringence. The discotic compounds have various alignment forms. Therefore, an optical compensatory sheet using the discotic compounds can have a specific optical characteristic that cannot be obtained by the conventional stretched birefringent film. Japanese Patent Provisional Publication No. 6(1994)-214116, and U.S. Patent Nos. 5,583,679, 5,646703 disclose the optical compensatory sheet using the discotic compounds.

The viewing angle of the liquid crystal display can be improved by using the above-mentioned optical compensatory sheet. However, the improved viewing angle is still inferior to that of CRT.

SUMMERY OF THE INVENTION

Japanese Patent Provisional Publication No. 2(1990)-176625 discloses a liquid crystal display using a liquid crystal cell of a vertical alignment (VA) mode, in which liquid crystal molecules are essentially vertically aligned while not applying voltage to the cell, and are essentially horizontally aligned while applying voltage to the cell. The vertical alignment liquid crystal mode is characterized in a wide viewing angle and a fast response, compared with the conventional liquid crystal modes. A prototype of the liquid crystal display of a vertical alignment mode has been exhibited (Nikkei Microdevice (written in Japanese), No. 136, page 147, 1996).

Though the liquid crystal display of a vertical alignment mode has a wide viewing angle compared with the conventional liquid crystal displays, a further improvement is necessary to be comparable with CRT.

It might be considered that an optical compensatory sheet is used to improve the viewing angle of the liquid crystal display of a vertical alignment mode in the same manner as in the conventional liquid crystal displays. However, the known optical compensatory sheets used in the conventional liquid crystal displays are not effective, or cause a serious problem in the liquid crystal display of a vertical alignment mode.

Even if the liquid crystal display of a vertical alignment mode has a stretched birefringent film (for example, an optically negative uniaxial compensatory sheet having an optic axis parallel to a normal line of the film) as an optical com-

pensatory sheet, the viewing angle would scarcely be improved.

It has been proposed to use an optical compensatory sheet comprising a transparent substrate and an optically anisotropic layer containing a discotic compound in place of the stretched birefringent film. However, the known optical compensatory sheet using the discotic compound causes a problem on a front contrast of a displayed image (a contrast of an image when the image is viewed along the normal line of the image) when the liquid crystal display of a vertical alignment mode is used as a normally black mode.

According to vertical alignment mode, liquid crystal molecules are essentially horizontally aligned to display white or half tone by applying voltage to the cell. The optical compensatory sheet needs a certain optical anisotropy to optically compensate an optical anisotropy of the liquid crystal cell while applying voltage to the cell. As a result, an optically anisotropic layer of the sheet has a certain retardation value in plane.

On the other hand, a retardation value in plane can be reduced as possible to display black while not applying voltage to the cell. If the retardation value is large, the transmittance increases to degrade the front contrast when a black and white image is displayed.

If the above-mentioned two requirements, which seems to be inconsistent are not satisfied, an optical compensatory sheet causes a problem on an image displayed on a liquid crystal cell of a vertical alignment mode. In practice, the known optical compensatory sheet degrades the contrast of the image of the vertical alignment mode.

An object of the present invention is to further improve the excellent viewing angle of a liquid crystal display of a vertical alignment mode without degrading a front contrast of an image.

Another object of the invention is to provide an optical compensatory sheet suitable for a liquid crystal display of a vertical alignment mode.

The present invention provides a liquid crystal display comprising a liquid crystal cell of a vertical alignment mode, two optical compensatory sheets arranged on both sides of the liquid crystal cell and two polarizing elements arranged on the optical compensatory sheets, said liquid crystal cell containing liquid crystal molecules, which are essentially vertically aligned while not applying voltage to the cell, and are essentially horizontally aligned while applying voltage to the cell,

wherein each of the optical compensatory sheets comprises a transparent substrate and an optically anisotropic layer containing a discotic compound, said optically anisotropic layer having an optical anisotropy to optically compensate an optical anisotropy of the liquid crystal cell while applying voltage to the cell, and each of said optical compensatory sheets having a retardation value in plane in the range of -5 to 5 nm.

The invention also provides a liquid crystal display comprising a liquid crystal cell of a vertical alignment mode, an optical compensatory sheets arranged on one side of the liquid crystal cell and two polarizing elements arranged on the liquid crystal cell and the optical compensatory sheet, said liquid crystal cell containing liquid crystal molecules, which are essentially vertically aligned while not applying voltage to the cell, and are essentially horizontally aligned while applying voltage to the cell,

wherein the optical compensatory sheet comprises a transparent substrate and an optically anisotropic layer containing a discotic compound, said optically anisotropic layer having an optical anisotropy to optically compensate an optical anisotropy of the liquid crystal cell while applying voltage to the cell, and said optical compensatory sheet having a retardation value in plane in the range of -10 to 10 nm.

The invention further provides an optical compensatory sheet comprising a transparent substrate and an optically anisotropic layer containing a discotic compound,

wherein the optically anisotropic layer and the transparent substrate are so arranged that slow axis of the optically anisotropic layer is essentially perpendicular to slow axis of the transparent substrate, and each of the optically anisotropic layer and the transparent substrate has retardation in plane satisfying the following formula:

$$|Re^1 - Re^2| \leq 10 \text{ nm}$$

in which Re^1 is an absolute retardation value of the optically anisotropic layer in plane and Re^2 is an absolute retardation value of the transparent substrate in plane.

In the present specification, the term "essentially vertically (or horizontally) aligned" and the term "essentially perpendicular" mean that a margin for error based on the exactly vertical, horizontal or perpendicular angle is in the range of ±20°. The margin for error is preferably in the range of ±15°, more preferably in the range of ±10°, and most preferably in the range of ±5°.

In the specification, alignment of liquid crystal molecules means that the average aligned angle of the compounds is included in the above-mentioned range, even if aligned angles of some compounds are outside the range. In practice, all the liquid crystal molecules are not always aligned along a single direction, as is described below.

In the specification, the term "slow axis" means the direction showing the maximum refractive index.

The present inventor has studied a liquid crystal display of a vertical alignment mode and an optical compensatory sheet, and has found that two optical characteristics (a certain optical anisotropy while applying voltage to the cell and

a small retardation value in plane while not applying voltage to the cell) required for an optical compensatory sheet used in a liquid crystal display of a vertical alignment mode can be satisfied without inconsistency.

The optically anisotropic layer of the optical compensatory sheet needs a certain optical anisotropy to optically compensate an optical anisotropy of the liquid crystal cell while applying voltage to the cell. Even if voltage is applied to the liquid crystal cell, some liquid crystal molecules are obliquely aligned (not horizontally aligned). The obliquely aligned liquid crystal molecules cause a positive optical anisotropy in a liquid crystal cell. As a result, the optical characteristic (viewing angle) of the cell is asymmetric. The positive optical anisotropy is compensated by an optically anisotropic layer, in more detail by a negative optical anisotropy of a discotic compound. The discotic compound is aligned corresponding to the alignment of the liquid crystal molecule of the cell. Therefore, the optically anisotropic layer containing the discotic compound has a certain retardation value in plane.

On the other hand, a retardation value in plane can be reduced when voltage is not applied to the cell. In the case that two optical compensatory sheets are arranged on both sides of the liquid crystal cell (the first embodiment of the present invention), each of the optical compensatory sheets should have a retardation value in plane in the range of -5 to 5 nm. In the case that one optical compensatory sheet is arranged on one side of the liquid crystal cell (the second embodiment of the present invention), the optical compensatory sheet should have a retardation value in plane in the range of -10 to 10 nm. Even though the optically anisotropic layer has a certain retardation value in plane, the retardation value in plane of the optical compensatory sheet can be reduced by adjusting a retardation value in plane of a transparent substrate and arranging the directions of the optically anisotropic layer and the transparent substrate. The retardation value in plane of the transparent substrate can easily be adjusted by stretching (preferably biaxially stretching) a transparent film.

For the reasons mentioned above, the excellent viewing angle of a liquid crystal display of a vertical alignment mode is further improved in the liquid crystal display of the present invention without degrading the contrast of the image.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a sectional view schematically illustrating alignment of liquid crystal molecules when voltage is not applied to a vertically aligned liquid crystal cell.

Fig. 2 is a sectional view schematically illustrating alignment of liquid crystal molecules when voltage is applied to a vertically aligned liquid crystal cell.

Fig. 3 schematically illustrates a refractive index ellipsoid obtained by viewing a liquid crystal cell vertical alignment mode and a polarizing element of crossed nicols arrangement along a normal line of a cell substrate.

Fig. 4 schematically illustrates a refractive index ellipsoid of a positive uniaxial liquid crystal cell and a refractive index ellipsoid of a negative uniaxial optical compensatory sheet.

Fig. 5 is a sectional view schematically illustrating combinations of a liquid crystal cell of a vertical alignment mode and an optical compensatory sheet of the first embodiment of the present invention.

Fig. 6 is a sectional view schematically illustrating combinations of a liquid crystal sell of a vertical alignment mode and an optical compensatory sheet of the second embodiment of the present invention.

Fig. 7 is a sectional view schematically illustrating a representative embodiment of an optical compensatory sheet.

Fig. 8 is a sectional view schematically illustrating a representative embodiment of a liquid crystal display.

DETAILED DESCRIPTION OF THE INVENTION

A liquid crystal display of a vertical alignment mode and an optical compensatory sheet are described by referring to the drawings.

Fig. 1 is a sectional view schematically illustrating alignment of liquid crystal molecules when voltage is not applied to a vertically aligned (VA) liquid crystal cell.

As is shown in Fig. 1, a liquid crystal cell comprises an upper substrate (11), a lower substrate (13) and liquid crystal molecules (12) sealed between the substrates. The liquid crystal molecules (12) used in a VA liquid crystal cell generally has a negative dielectric constant anisotropy. When voltage is not applied to a VA liquid crystal cell, the liquid crystal molecules (12) are vertically aligned. Where a pair of polarizing elements (not shown in Fig. 1) are arranged on both sides of the upper and lower substrates (11, 13), no retardation is caused along a normal line (14) of the substrate surface. As a result, light is not transmitted along the normal line (14) to display black.

If the cell is viewed along a direction (15) inclined from the normal line (14), retardation is caused to transmit light. As a result, a contrast of an image is degraded. The retardation along the inclined direction (15) can be compensated with an optical anisotropy of an optical compensatory sheet. The details are described below referring to Fig. 4.

Fig. 1 shows that all the liquid crystal molecules (12) are completely vertically aligned. However, the aligned compounds are slightly slanted (pretilted) to a direction. The slanted compounds can be aligned to the pretilted direction

when voltage is applied to a VA liquid crystal cell (described below referring to Fig. 2).

Fig. 2 is a sectional view schematically illustrating alignment of liquid crystal molecules when voltage is applied to a vertically aligned (VA) liquid crystal cell.

Each of an upper substrate (21) and a lower substrate (23) has an electrode layer (not shown in Fig. 2) to apply voltage to liquid crystal molecules (22). As is shown in Fig. 2, the liquid crystal molecules placed in the middle of the cell are horizontally aligned by applying voltage to the cell. As a result, retardation is caused along a normal line (24) of the substrate surface to transmit light.

Each of an upper substrate (21) and a lower substrate (23) further has an orientation layer (not shown in Fig. 2) having a function of aligning the liquid crystal molecules (22) vertically. Accordingly, the liquid crystal molecules near the orientation layer are not horizontally aligned, but obliquely aligned along a pretilted direction, though the molecules placed in the middle of the cell are horizontally aligned. If the cell is viewed along a direction (25) inclined from the normal line (24), change of the angle of retardation is relatively small. On the other hand, change of the angle of retardation is relatively large where the cell is viewed along another direction (26). If the pretilted direction (the same as 26) is placed along downward direction in an image, viewing angles along leftward and rightward directions would be wide and symmetrical, a viewing angle along a downward direction would be wide, but a viewing angle an upward direction would be narrow so that the viewing angles along downward and upward directions would be asymmetrical. The retardation caused by the obliquely (not horizontally) aligned liquid crystal molecules while applying voltage to the cell should be compensated to correct the asymmetrical viewing angles (asymmetrical transmittance).

The optical compensatory sheet of the present invention has a function of compensating the above-mentioned retardation to improve the viewing angle (correcting the asymmetrical viewing angle while applying voltage to the cell).

Fig. 3 schematically illustrates a refractive index ellipsoid obtained by viewing a liquid crystal cell of a vertical alignment mode and a polarizing element of crossed nicols arrangement along a normal line of a cell substrate. Fig. 3(a) shows a refractive index ellipsoid when voltage is not applied to the cell, and Fig. 3(b) shows a refractive index ellipsoid when voltage is applied to the cell.

As is shown in Fig. 3, a transmission axis on an incident side (31a, 31b) of a polarizing element is arranged perpendicular to a transmission axis on the other side (32a, 32b) of a polarizing element according to crossed nicols arrangement.

The liquid crystal molecules are vertically aligned (perpendicular to the substrate surface) when voltage is not applied to the cell. A refractive index ellipsoid (33a) has a circular shape shown in Fig. 3(a) when voltage is not applied to the cell. Therefore, the liquid crystal cell having no retardation shown in Fig. 3(a) does not transmit light.

On the other hand, most of the liquid crystal molecules are horizontally aligned (parallel to the substrate surface) when voltage is applied to the cell. A refractive index ellipsoid (33b) has an oval shape shown in Fig. 3(b) when voltage is applied to the cell. Therefore, the liquid crystal cell having a retardation shown in Fig. 3(b) transmits light along a direction (34), which is an orthographic projection of an optic axis of the liquid crystal molecule in the cell to the cell substrate surface.

Fig. 4 schematically illustrates a refractive index ellipsoid of a positive uniaxial liquid crystal cell and a refractive index ellipsoid of a negative uniaxial optical compensatory sheet.

Where a positive uniaxial optical anisotropy is caused in a liquid crystal cell (43), a refractive index ellipsoid (44), which is formed by refractive indexes in plane (44x, 44y) and a refractive index along a vertical direction (44z) has a shape like a standing football. If a liquid crystal cell having a football-like (not spherical) refractive index ellipsoid is viewed along an inclined direction (15 in Fig. 1), retardation is caused in the cell. The retardation is canceled by a negative uniaxial optical compensatory sheet (42) to prevent transmission of light.

The negative uniaxial optical compensatory sheet (42) has a refractive index ellipsoid (41) having a shape like a pressed beach ball, which is formed by refractive indexes in plane (41x, 41y) and a refractive index along a vertical direction (41z). Therefore, the sum of 41x and 44x, the sum of 41y and 44y and the sum 41z and 44z are identical values. As a result, the retardation caused in the liquid crystal cell is canceled.

The optical compensatory sheet of the present invention has another function of preventing transmission of light incident from an inclined direction when voltage is not applied to the cell as well as a function of improving the viewing angle when voltage is not applied to the cell (described above referring to Fig. 2).

Fig. 5 is a sectional view schematically illustrating combinations of a liquid crystal cell of a vertical alignment mode and an optical compensatory sheet of the first embodiment of the present invention.

As is shown in Fig. 5, the optical compensatory sheets (53, 54) of the first embodiment are combined with a VA liquid crystal cell (50) according to four variations (a) to (d).

According to the variations (a) and (c), optically anisotropic layers (51) containing a discotic compound of the optical compensatory sheets (53, 54) are attached to the VA liquid crystal cell (50). In the variation (a), the discotic compound is aligned by an orientation layer (not shown in Fig. 5) arranged between the optically anisotropic layer (51) and the transparent substrate (52). In the variation (c), the discotic compound is aligned by an orientation layer (not shown in Fig. 5) arranged between the optically anisotropic layer (51) and the VA liquid crystal cell (50).

According to the variations (b) and (d), transparent substrates (52) of the optical compensatory sheets (53, 54) are attached to the VA liquid crystal cell (50). In the variation (b) the discotic compound is aligned by an orientation layer (not shown in Fig. 5) arranged between the optically anisotropic layer (51) and the transparent substrate (52). In the variation (c), the discotic compound is aligned by an orientation layer (not shown in Fig. 5) arranged outside the optically anisotropic layer (51).

Fig. 6 is a sectional view schematically illustrating combinations of a liquid crystal cell of a vertical alignment mode and an optical compensatory sheet of the second embodiment of the present invention.

As is shown in Fig. 6, the optical compensatory sheet (63) of the second embodiment is combined with a VA liquid crystal cell (60) according to four variations (e) to (h).

According to the variations (e) and (g), an optically anisotropic layer (61) containing a discotic compound of the optical compensatory sheet (63) is attached to the VA liquid crystal cell (60). In the variation (e), the discotic compound is aligned by an orientation layer (not shown in Fig. 6) arranged between the optically anisotropic layer (61) and the transparent substrate (62). In the variation (g), the discotic compound is aligned by an orientation layer (not shown in Fig. 6) arranged between the optically anisotropic layer (61) and the VA liquid crystal cell (60).

According to the variations (f) and (h), a transparent substrate (62) of the optical compensatory sheet (63) is attached to the VA liquid crystal cell (60). In the variation (f), the discotic compound is aligned by an orientation layer (not shown in Fig. 6) arranged between the optically anisotropic layer (61) and the transparent substrate (62). In the variation (h), the discotic compound is aligned by an orientation layer (not shown in Fig. 6) arranged outside the optically anisotropic layer (61).

Fig. 7 is a sectional view schematically illustrating a representative embodiment of an optical compensatory sheet.

The optical compensatory sheet shown in Fig. 7 comprises a transparent substrate (71), an orientation layer (72) and an optically anisotropic layer (73) in the order. The layered structure corresponds to (a) and (b) in Fig. 5 and (e) and (f) in Fig. 6. The orientation layer (72) has an aligning function caused by rubbing the layer along a direction (75).

Discotic compounds (73a, 73b, 73c) contained in the optically anisotropic layer (73) are planer molecules. Each of the molecules has only one plane, namely discotic plane (Pa, Pb, Pc). The discotic planes (Pa, Pb, Pc) are inclined to planes (71a, 71b, 71c) parallel to the surface of the transparent substrate (71). The angle between the discotic planes (Pa, Pb, Pc) and the paralleled planes (71a, 71b, 71c) are inclined angles (θa, θb, θc). As the distance between the molecule and the orientation layer (72) increases along a normal line (74) of the transparent substrate (71), the inclined angles increases ($\theta a<\theta b<\theta c$).

The inclined angles (θa, θb, θc) are preferably in the range of 0 to 60°. The minimum inclined angle is preferably in the range of 0 to 55°, and more preferably in the range of 5 to 40°. The maximum inclined angle is preferably in the range of 5 to 60°, and more preferably in the range of 20 to 60°. The difference between the minimum and maximum angles is preferably in the range of 5 to 55°, and more preferably in the range of 10 to 40°.

An optical compensatory sheet has a function of improving the viewing angle. The function can be further improved where the inclined angles are changed as is shown in Fig. 7. The optical compensatory sheet shown in Fig. 7 has another function of preventing an image from reversion, gray-scale inversion and color contamination of a displayed image.

Fig. 8 is a sectional view schematically illustrating a representative embodiment of a liquid crystal display.

The liquid crystal display shown in Fig. 8 comprises a liquid crystal cell of a vertical alignment mode (VAC), a pair of polarizing elements (A, B) arranged on both sides of the liquid crystal cell, a pair of optical compensatory sheets (OC1, OC2) arranged between the liquid crystal cell and the polarizing elements, and a back light (BL). According to the first embodiment of the present invention, the pair of the optical compensatory sheets (OC1, OC2) are arranged, as is shown in Fig. 8. However, only one optical compensatory sheet can be arranged on one side of the liquid crystal cell (the second embodiment of the present invention).

The arrows (R1, R2) in the optical compensatory sheets (OC1, OC2) mean rubbing directions of orientation layers (corresponding to the arrow 75 in Fig. 7) provided on the optical compensatory sheets. In the liquid crystal display shown in Fig. 8, an optically anisotropic layers of the optical compensatory sheets (OC1, OC2) are attached to the liquid crystal cell (VAC). The optically anisotropic layers can also be attached to the polarizing elements (A, B). The rubbing directions of an orientation layer (R1, R2) should be reversed where the optically anisotropic layers are attached to the polarizing elements.

The arrows (RP1, RP2) in the liquid crystal cell (VAC) mean the rubbing directions of orientation layers provided on the cell substrates.

The arrows (PA, PB) in the polarizing elements (A, B) mean the transmission axes of light polarized in the elements.

The rubbing directions in the optical compensatory sheets (R1, R2) is preferably essentially parallel (or reversely parallel) to the rubbing directions in the liquid crystal cell (RP1, RP2). The transmission axes of the polarizing elements (PA, PB) are preferably essentially parallel or perpendicular to each other.

The term "essentially parallel (or reversely parallel) or perpendicular" means that a margin for error based on the exactly parallel (or reversely parallel) or perpendicular angle is in the range of ±20°. The margin for error is preferably

in the range of ±15°, more preferably in the range of ±10°, and most preferably in the range of ±5°.

The angle between the rubbing directions in the liquid crystal cell (RP1, RP2) and the transmission axes of the polarizing elements (PA, PB) is preferably in the range of 10 to 80°, more preferably in the range of 20 to 70°, and most preferably in the range of 35 to 55°.

[Optical compensatory sheet]

The optical compensatory sheet comprises a transparent substrate and an optically anisotropic layer containing a discotic compound.

The optical compensatory sheet has a direction of the minimum retardation, which is preferably not present in plane and not present along a normal line of the sheet.

The optical characteristic of the optical compensatory sheet depends on optical characteristics of the optically anisotropic layer and the transparent substrate and on arrangement of the layer and the substrate. The optical characteristics are described below.

The optical characteristics of (1) the optical anisotropic layer, (2) the transparent substrate and (3) the optical compensatory sheet include an absolute retardation value in plane (Re), an absolute Rth retardation value (Rth) and an angle between a direction of the minimum retardation and a normal line of the sheet (β).

The absolute retardation value in plane (Re) is defined in the following formula:

$$Re = |\{(nx-ny)\times d|$$

in which each of nx and ny is the principal refractive index in plane (of the optical anisotropic layer, the transparent substrate or the optical compensatory sheet), and d is the thickness (of the optical anisotropic layer, the transparent substrate or the optical compensatory sheet).

The absolute Rth retardation value (Rth) is defined in the following formula:

$$Rth = |[\{(n1+n2)/2\}-n3]\times d|$$

in which each of n1, n2 and n3 is the principal refractive index in a refractive index ellipsoid approximately obtained from optical anisotropy (of the optical anisotropic layer, the transparent substrate or the optical compensatory sheet), n3 is the minimum index, and d is the thickness (of the optical anisotropic layer, the transparent substrate or the optical compensatory sheet). If the inclined angle of the discotic compound were 0°, each of n1 and n2 would correspond to the principal refractive index in plane (of the optical anisotropic layer or the transparent substrate), and n3 would correspond to the principal refractive index (of the optical anisotropic layer or the transparent substrate).

According to the first embodiment of the present invention, the optical compensatory sheet has a retardation value in plane in the range of -5 to 5 nm. Therefore, the absolute retardation value in plane of the optical compensatory sheet (Re^{31}) should satisfy the formula of $0 \leq R^{31} \leq 5$.

The optically anisotropic layer and the transparent substrate are preferably so arranged that slow axis of the optically anisotropic layer is essentially perpendicular to slow axis of the transparent substrate to adjust Re^{31} within the above-mentioned range. Further, each of the optically anisotropic layer and the transparent substrate preferably has retardation in plane satisfying the following formula:

$$|Re^1 - Re^2| \leq 5 \text{ nm}$$

in which Re^1 is an absolute retardation value in plane of the optically anisotropic layer, and Re^2 is an absolute retardation value in plane of the transparent substrate.

According to the second embodiment of the present invention, the optical compensatory sheet has a retardation value in plane in the range of -10 to 10 nm. Therefore, the absolute retardation value in plane of the optical compensatory sheet (Re^{32}) should satisfy the formula of $0 \leq R^{32} \leq 10$.

The optically anisotropic layer and the transparent substrate are preferably so arranged that slow axis of the optically anisotropic layer is essentially perpendicular to slow axis of the transparent substrate to adjust Re^{32} within the above-mentioned range. Further, each of the optically anisotropic layer and the transparent substrate preferably has retardation in plane satisfying the following formula:

$$|Re^1 - Re^2| \leq 10 \text{ nm}$$

in which Re^1 is an absolute retardation value in plane of the optically anisotropic layer, and Re^2 is an absolute retardation value in plane of the transparent substrate.

Preferred optical characteristics of (1) the optical anisotropic layer, (2) the transparent substrate and (3) the optical compensatory sheet are shown below. The unit of Re and Rth is nm. The superscripted number 1 means a value of the optical anisotropic layer, the superscripted number 2 means a value of the transparent substrate and the superscripted number 3 means a value of the optical compensatory sheet. The meanings of R^{31} and R^{32} are described above.

Preferred range	More preferred	Most preferred
$0 < Re^1 \leq 200$	$5 \leq Re^1 \leq 150$	$10 \leq Re^1 \leq 100$
$0 \leq Re^2 \leq 200$	$5 \leq Re^2 \leq 150$	$10 \leq Re^2 \leq 100$
$0 \leq Re^{31} \leq 4.5$	$0 \leq Re^{31} \leq 4$	$0 \leq Re^{31} \leq 3.5$
$0 \leq Re^{32} \leq 9$	$0 \leq Re^{32} \leq 8$	$0 \leq Re^{32} \leq 7$
$10 \leq Rth^1 \leq 400$	$20 \leq Rth^1 \leq 300$	$30 \leq Rth^1 \leq 200$
$20 \leq Rth^2 \leq 400$	$50 \leq Rth^2 \leq 350$	$100 \leq Rth^2 \leq 300$
$10 \leq Rth^3 \leq 600$	$60 \leq Rth^3 \leq 500$	$100 \leq Rth^3 \leq 400$
$0° < \beta^1 \leq 60°$	$0° < \beta^1 \leq 50°$	$0° < \beta^1 \leq 40°$
$0° \leq \beta^2 \leq 10°$	$0° \leq \beta^2 \leq 5°$	$0° \leq \beta^2 \leq 3°$
$0° < \beta^3 \leq 50°$	$0° < \beta^3 \leq 45°$	$0° < \beta^3 \leq 40°$

In the case that the optical compensatory sheet has two or more transparent substrates, the total retardation value in plane of the substrates (Re2) corresponds to the sum of the values of individual substrates.

The optical compensatory sheet preferably comprises a transparent substrate and an optically anisotropic layer, each of which have the above-mentioned optical characteristics. The optical compensatory sheet usually further comprises an orientation layer. The orientation layer is preferably arranged between the transparent substrate and the optically anisotropic layer. However, the orientation layer can also be arranged on the optically anisotropic layer. After the orientation layer aligns discotic compound contained in the optically anisotropic layer, alignment of the discotic compounds can be kept even if the orientation layer is removed from the optical compensatory sheet. Accordingly, the orientation layer is essential in the preparation of the optical compensatory sheet, but is not essential in the prepared sheet.

In the case that an orientation layer is arranged between the transparent substrate and the optically anisotropic layer, an undercoating layer (adhesive layer) is preferably further provided between the transparent substrate and the orientation layer. A protective layer may be provided on the optically anisotropic layer or on the back surface of the transparent substrate.

The optically anisotropic layer, the orientation layer and the transparent substrate are described below.

[Optically anisotropic layer]

The optically anisotropic layer contains a discotic compound. The discotic compound preferably is negative uniaxial, and preferably is obliquely aligned. The discotic compound preferably has a hybrid alignment shown in Fig. 7, wherein the inclined angles (between the discotic planes and the planes parallel to the transparent substrate) are changed along a normal line of the transparent substrate. The discotic compound has an optic axis along a normal line of the discotic plane. The birefringence along the discotic plane is larger than that along the optic axis.

An optically anisotropic layer is preferably formed by aligning a discotic compound by an orientation layer, and fixing the alignment of the discotic compound. The discotic compound is fixed preferably by a polymerization reaction.

The minimum retardation value in the optically anisotropic layer is preferably larger than 0. In other words, a direction having retardation of 0 preferably is not present in the optically anisotropic layer.

The discotic (liquid crystal) compound is described in various documents (C. Destrade et al., Mol. Crysr. Liq. Cryst., vol. 71, page 111 (1981); Japan Chemical Society, Quarterly Chemical Review (written in Japanese), chapter 5 and chapter 10, section 2 (1994); B. Kohne et al., Angew. Chem. Soc. Chem. Comm., page 1794 (1985); and J. Zhang et al., J. Am. Chem. Soc., vol. 116, page 2655 (1994)). The polymerization reaction of the discotic compound is described in Japanese Patent Provisional Publication No. 8(1996)-27284.

A polymerizable group should be bound to a discotic core of the discotic compound to cause the polymerization reaction of the compound. However, if the polymerizable group is directly bound to the discotic core, it is difficult to keep

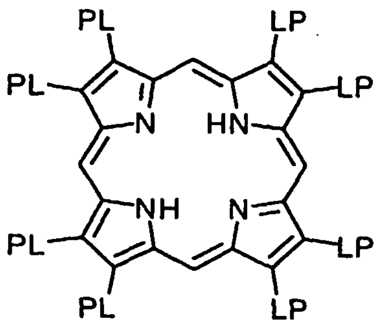
the alignment at the polymerization reaction. Therefore, a linking group is introduced between the discotic core and the polymerizable group. Accordingly, the discotic compound having a polymerizable group preferably is a compound represented by the following formula (I).

$$D(\text{-}L\text{-}P)_n \qquad \text{(I)}$$

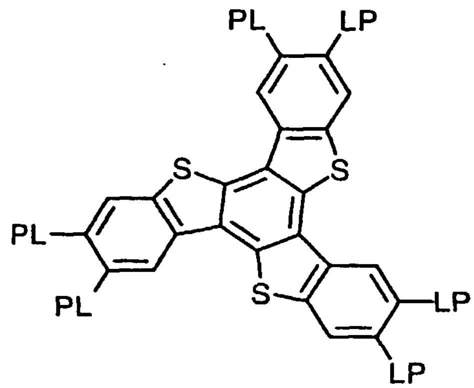
in which D is a discotic core; L is a divalent linking group; P is a polymerizable group; and n is an integer of 4 to 12.

Examples of the discotic cores (D) are shown below. In the examples, LP (or PL) means the combination of the divalent linking group (L) and the polymerizable group (P).

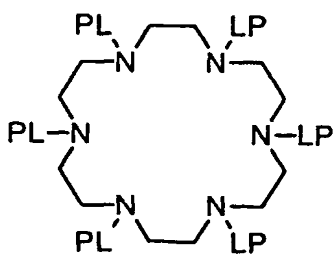
(D1)



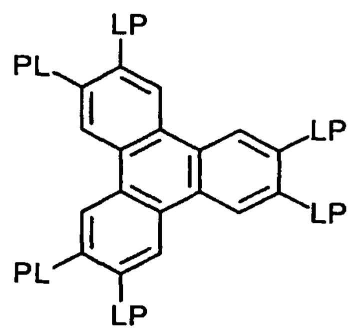
(D2)



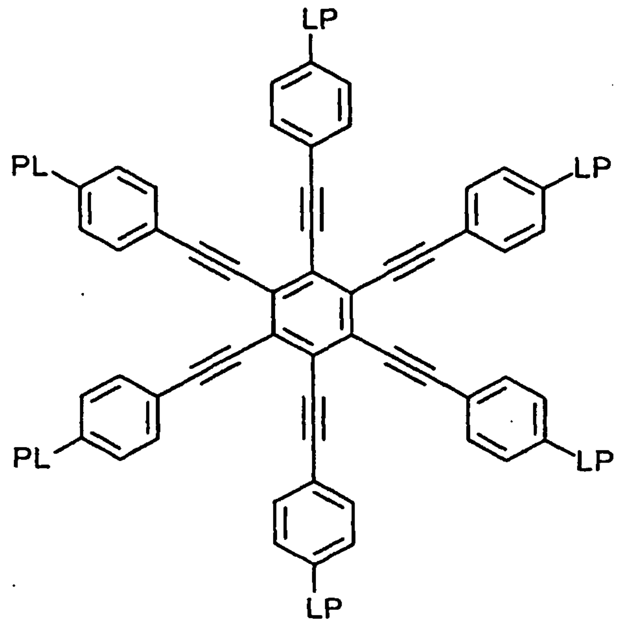
(D3)



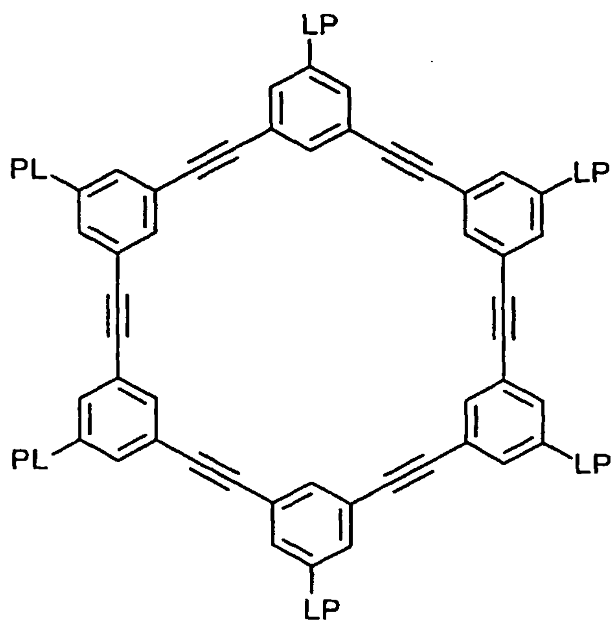
(D4)



(D5)



(D6)



In the formula (I), the divalent linking group (L) preferably is selected from the group consisting of an alkylene group, an arylene group, -CO-, -NH-, -O-, -S- and combinations thereof. L more preferably is a divalent linking group comprising at least two divalent groups selected from the group consisting of an alkylene group, an arylene group, -CO-, -NH-, -O- and -S-. L more preferably is a divalent linking group comprising at least two divalent groups selected from the group consisting of an alkylene group, an arylene group, -CO- and -O-. The alkylene group preferably has 1 to 12 car-

bon atoms. The arylene group preferably has 6 to 10 carbon atoms.

Examples of the divalent linking groups (L) are shown below. In the examples, the left side is attached to the discotic core (D), and the right side is attached to the polymerizable group (P).

L1:	-alkylene-CO-O-alkylene-O-CO-
L2:	-alkylene-CO-O-alkylene-O-
L3:	-alkylene-CO-O-alkylene-O-alkylene-
L4:	-alkylene-CO-O-alkylene-
L5:	-O-alkylene-O-CO-
L6:	-O-alkylene-O-
L7:	-O-alkylene-O-CO-NH-alkylene-
L8:	-O-alkylene-S-alkylene-
L9:	-O-alkylene-
L10:	-CO-arylene-O-alkylene-O-CO-
L11:	-CO-arylene-O-alkylene-
L12:	-CO-arylene-O-alkylene-O-
L13:	-CO-NH-alkylene-
L14:	-NH-alkylene-O-CO-
L15:	-NH-alkylene-O-
L16:	-S-alkylene-S-alkylene-
L17:	-S-alkylene-
L18:	-S-alkylene-O-
L19:	-O-CO-arylene-alkylene-O-CO-

The polymerizable group (P) is determined by the polymerization reaction. Examples of the polymerizable groups (P) are shown below.

(P1) $-CH=CH_2$

(P2) $-C\equiv CH$

(P3) $-CH_2-C\equiv CH$

(P4) $-NH_2$

(P5) $-SO_3H$

(P6) $-CH_2-\overset{O}{CH-CH_2}$ (epoxy: O bridging CH and CH_2)

(P7) $-C(CH_3)=CH_2$

(P8) $-CH=CH-CH_3$

(P9) $-N=C=S$

(P10) $-SH$

(P11) $-CHO$

(P12) $-OH$

(P13) $-CO_2H$

(P14) $-N=C=O$

The polymerizable group (P) preferably is an unsaturated polymerizable group (P1, P2, P3, P7, P8) or an epoxy group (P6), more preferably is an unsaturated polymerizable group, and most preferably is an ethylenically unsaturated group (P1, P7, P8).

In the formula (I), n is an integer of 4 to 12, which is determined by the chemical structure of the discotic core (D). The 4 to 12 combinations of L and P can be different from each other. However, the combinations are preferably identical.

An optically anisotropic layer can be formed by coating a solution containing the discotic compound, a polymerization initiator and other optional components on an orientation layer.

The optically anisotropic layer has a thickness preferably in the range of 0.5 to 100 μm, and more preferably in the

range of 0.5 to 30 µm.

The aligned discotic compound is preferably fixed while keeping the alignment. The compound is fixed preferably by a polymerization reaction. The polymerization reaction can be classified a thermal reaction using a thermal polymerization initiator and a photo reaction using a photo polymerization initiator. A photo polymerization reaction is preferred.

Examples of the photo polymerization initiators include α-carbonyl compounds (described in U.S. Patent Nos. 2,367,661, 2,367,670), acyloin ethers (described in U.S. Patent No. 2,448,828), α-hydrocarbon substituted acyloin compounds (described in U.S. Patent No. 2,722,512), polycyclic quinone compounds (described in U.S. Patent Nos. 2,951,758, 3,046,127), combinations of triarylimidazoles and p-aminophenyl ketones (described in U.S. Patent No. 3,549,367), acridine or phenazine compounds (described in Japanese Patent Provisional Publication No. 60(1985)-105667 and U.S. Patent No. 4,239,850) and oxadiazole compounds (described in U.S. Patent No. 4,212,970).

The amount of the photo polymerization initiator is preferably in the range of 0.01 to 20 wt.%, and more preferably in the range of 0.5 to 5 wt.% based on the solid content of the coating solution of the layer.

The light irradiation for the photo polymerization is preferably conducted by an ultraviolet ray. The exposure energy is preferably in the range of 20 to 5,000 mJ, and more preferably in the range of 100 to 800 mJ. The light irradiation can be conducted while heating the layer to accelerate the photo polymerization reaction.

[Orientation layer]

The orientation layer has a function of aligning discotic compounds. The orientation layer can be formed by rubbing treatment of an organic compound (preferably a polymer), oblique evaporation of an inorganic compound, formation of a micro groove layer, or stimulation of an organic compound (e.g., ω-tricosanoic acid, dioctadecylmethylammonium chloride, methyl stearate) according to a Langmuir-Blodgett method. Further, the aligning function of the orientation layer can be activated by applying an electric or magnetic field to the layer or irradiating the layer with light.

The orientation layer is preferably formed by rubbing a polymer. The polymer preferably is polyvinyl alcohol. A denatured polyvinyl alcohol having a hydrophobic group is particularly preferred. The discotic compound can uniformly be aligned by introducing the hydrophobic group into polyvinyl alcohol because the hydrophobic group has an affinity with the discotic compound. The hydrophobic group is attached to the side chain or the end of the main chain of polyvinyl alcohol.

The hydrophobic group preferably is an aliphatic group (more preferably an alkyl group or an alkenyl group) having 6 or more carbon atoms or an aromatic group.

In the case that the hydrophobic group is attached to the end of the main chain, a linking group is preferably introduced between the hydrophobic group and the end of the main chain. Examples of the linking group include -S-, -C(CN)R^1-, -NR^2-, -CS- and combinations thereof. Each of R^1 and R^2 is hydrogen or an alkyl group having 1 to 6 carbon atoms, and preferably is an alkyl group having 1 to 6 carbon atoms.

In the case that the hydrophobic group is attached to the side chain, the acetyl group of the vinyl acetate units in polyvinyl alcohol is partially replaced with an acyl group (-CO-R^3) having 7 or more carbon atoms. R^3 is an aliphatic group having 6 or more carbon atoms or an aromatic group.

Commercially available denatured polyvinyl alcohols (e.g., MP103, MP203, R1130, Kuraray Co., Ltd.) can be used in the orientation layer.

The (denatured) polyvinyl alcohol has a saponification degree preferably of not smaller than 80%. The (denatured) polyvinyl alcohol has a polymerization degree preferably of not smaller than 200.

The rubbing treatment can be conducted by rubbing the layer with a paper or cloth several times along a certain direction. A cloth is preferred to a paper. The cloth preferably uniformly contains uniform (about length and thickness) fibers.

[Transparent substrate]

A transparent substrate preferably is a polymer film made of a transparent polymer of positive inherent birefringence. The transparent substrate means that light transmittance is not less than 80%.

A polymer film made of a polymer of positive inherent birefringence usually has a (negative) refractive index ellipsoid having a shape like a pressed beach ball. The film has one or two optic axes along a normal line of the film. In the present invention, the above-mentioned polymer film is preferably used as the substrate in combination with an optical anisotropic layer containing a discotic compound, which has a negative inherent birefringence and an optical axis along a normal line of a discotic plane.

Examples of the polymers include polycarbonate, polyarylate, polysulfone, polyethersulfone, diacetyl cellulose and triacetyl cellulose. Polycarbonate and diacetyl cellulose and triacetyl cellulose are preferred. The polymer film is formed preferably according to a solvent casting method.

The transparent substrate preferably has an absolute retardation value in plane (Re^2) analogous to an absolute retardation value in plane of an optical anisotropic layer (Re^1). The retardation of the transparent substrate can be adjusted by a stretching (preferably biaxially stretching) treatment or by adjusting the shrinkage ratio along a longtitudinal or horizontal direction. The retardation can easily be adjusted by subjecting a polycarbonate film to an unbalanced biaxially stretching process.

The transparent substrate can be subjected to a surface treatment (e.g., glow discharge treatment, corona discharge treatment, ultraviolet (UV) treatment, flame treatment) to improve adhesion to a layer formed on the substrate (e.g., adhesive layer, orientation layer, optically anisotropic layer). A glow discharge treatment or a corona discharge treatment is preferred. Two or more surface treatments can be used in combination.

The transparent substrate has a thickness preferably in the range of 20 to 500 μm, and more preferably in the range of 50 to 200 μm.

An adhesive layer (undercoating layer) can be provided on the transparent substrate. The adhesive layer is preferably formed by coating a hydrophilic polymer (e.g., gelatin) on the transparent substrate.

The undercoating layer has a thickness preferably in the range of 0.1 to 2 μm, and more preferably in the range of 0.2 to 1 μm.

[Liquid crystal cell]

The present invention uses a vertically aligned (VA) liquid crystal cell. In the liquid crystal cell of a vertical alignment mode, a liquid crystal molecule is essentially vertically aligned while not applying voltage to the cell, and is essentially horizontally aligned while applying voltage to the cell. The liquid crystal molecule used in the VA cell usually has a negative dielectric anisotropy.

The product (Δnxd) of a refractive anisotropy (Δn) of the liquid crystal molecule and a thickness (d) of the liquid crystal layer of the liquid crystal cell is preferably in the range of 100 to 1,000 nm, more preferably in the range of 150 to 400 nm, and most preferably in the range of 200 to 350 nm to satisfy the brightness and the viewing angle.

The liquid crystal cell of a vertical alignment mode is used according to a normally white (NW) mode or a normally black (NB) mode. The present invention is particularly effective in the normally black mode.

[Liquid crystal display]

A liquid crystal display comprises a liquid crystal cell, a pair of optically compensatory sheets arranged on both sides of the cell (the first embodiment of the present invention) or an optically compensatory sheets arranged on one side of the cell, and a pair of polarizing elements arranged on the liquid crystal cell or the optical compensatory sheet.

The liquid crystal display include a direct looking type, a projection type and a modulation type. The present invention is also effective in a liquid crystal display having an active matrix such as TFT, MIM having three or two terminals.

The degree of wavelength dispersion of the liquid crystal cell is preferably analogous to the degree of wavelength dispersion of the optical compensatory sheet. In more detail, each of the liquid crystal cell and the optical compensatory sheet has a degree of a wavelength dispersion satisfying the following formula:

$$0.8 \leq \alpha 2/\alpha 1 \leq 1.3$$

in which α1 is a degree of a wavelength dispersion of the liquid crystal cell, which is a ratio (Re450/Re550) of a retardation value of the cell at the wavelength of 450 nm (Re450) to a retardation value of the cell at the wavelength of 550 nm (Re550), and α2 is a degree of a wavelength dispersion of the optical compensatory sheet, which is a ratio (Re450/Re550) of a retardation value of the sheet at the wavelength of 450 nm (Re450) to a retardation value of the sheet at the wavelength of 550 nm (Re550).

EXAMPLE 1

(Formation of transparent substrate)

In dichloromethane, 2,2'-bis(4-hydroxyphenyl)propane polycarbonate resin (viscosity average molecular weight: 28,000) was dissolved to obtain a 18 wt.% solution. The obtained solution was cast on a band, dried at 50°C for 10 minutes, peeled from the band, and dried at 100°C for 10 minutes. The obtained film was stretched by 7% along a longitudinal direction at 170°C, and was stretched by 5% along a horizontal direction at 175°C to obtain a biaxially stretched roll film (transparent substrate) having the thickness of 100 μm. The longitudinal stretching was controlled by the difference between the rotating speeds of two chucking rolls. The horizontal stretching was controlled by the width of a tenter.

The retardation of the transparent substrate was measured by using an ellipsometer (AEP-100). The retardation in

plane was -12 nm (Re^2 = 12) and the Rth retardation was 120 nm (Rth^2 = 120). The directions of nx and ny were present in the plane and the direction of nx was parallel to the normal line of the transparent substrate. The angle between the direction of the minimum retardation and the normal line of the substrate (β^2) was 0°.

(Surface treatment of transparent substrate)

The both surfaces of the transparent substrate (width: 30 cm) were subjected to a corona discharge treatment at room temperature by using a solid state corona discharger (6KVA, Pillar). The treatment speed was 20 m per minute, and the treatment condition was 0.375 kV • A • minute per m^2. The treatment cycle was 9.6 kHz, and the gap clearance between an electrode and a dielectric roll was 1.6 mm.

(Formation of adhesive layer)

A coating solution of the following composition was coated on the surface treated transparent substrate by using a wire bar. The coating amount was 10 ml per m^2. The coated layer was dried at 115°C for 2 minutes to form an adhesive layer.

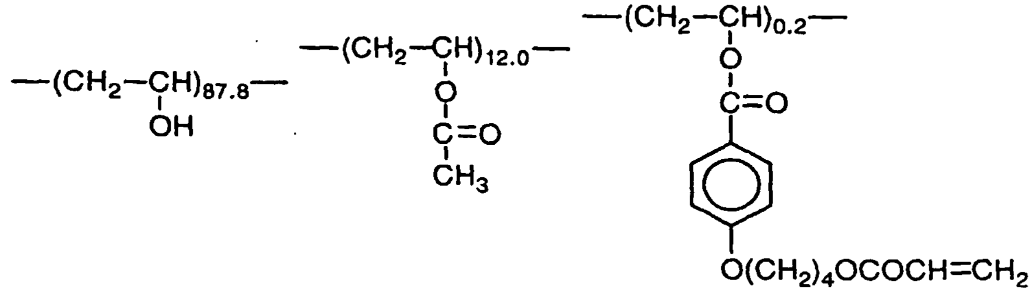
Coating solution for adhesive layer	
Gelatin	1 weight part
Water	1 weight part
Acetic acid	1 weight part
Methanol	50 weight parts
Ethylene dichloride	50 weight parts
p-Chlorophenol	4 weight parts

(Formation of orientation layer)

A coating solution of the following composition was coated on the adhesive layer by using a slide coater. The coating amount was 10 ml per m^2. The coated layer was air dried at 60°C for 60 seconds, and further air dried at 90°C for 150 seconds to form an orientation layer.

Coating solution for orientation layer	
The following denatured polyvinyl alcohol	10 weight parts
Water	371 weight parts
Methanol	119 weight parts
Glutaric aldehyde (cross-linking agent)	0.5 weight part

(Denatured polyvinyl alcohol)

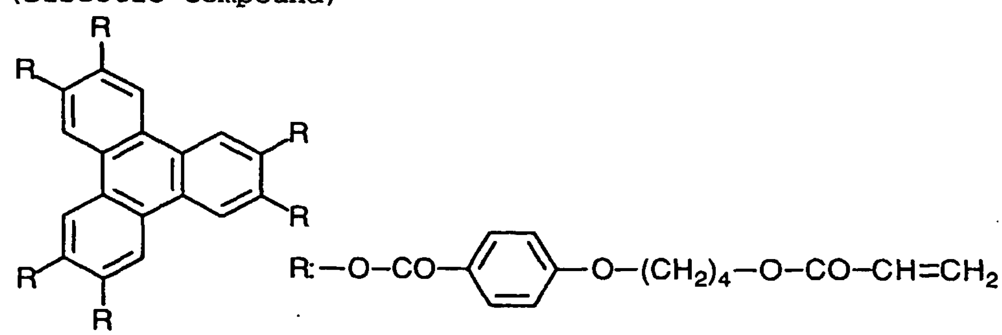


The formed layer was subjected to a rubbing treatment. The rubbing direction was parallel to the slow axis of the transparent substrate.

(Formation of optically anisotropic layer)

In 8.43 g of methyl ethyl ketone, 1.8 g of the following discotic (liquid crystal) compound, 0.2 g of trimethylolpropane triacrylate denatured with ethylene oxide (V#360, Osaka Organic Chemical Co., Ltd.), 0.04 g of cellulose acetate butyrate (CAB551-0.2, Eastman Chemical), 0.06 g of a photopolymerization initiator (Irgacure 907, Ciba-Geigy) and 0.02 g of a sensitizer (Kayacure DETX, Nippon Kayaku Co., Ltd.) were dissolved to prepare a coating solution. The coating solution was coated on the orientation layer by using a wire bar of #2.5. The sheet was adhered to a metal frame, and heated in a thermostat at 130°C for 2 minutes to align the discotic compound. The sheet was irradiated with an ultraviolet ray at 130°C for 1 minutes by using a high pressure mercury lamp of 120 W/cm. The sheet was cooled to room temperature to obtain an optical compensatory sheet (1).

(Discotic compound)



(Evaluation of optical compensatory sheet)

The thickness of the optically anisotropic layer was about 1.0 μm. The retardation value of the optically anisotropic layer was measured along the rubbing direction. As a result, a direction having retardation of 0 was not found in the optically anisotropic layer.

The average inclined angle of the optic axis of the optically anisotropic layer, namely the angle between the direction of the minimum retardation and the normal line of the sheet was 28° (β^1 = 28°). The retardation in plane was 15 nm (Re^1 = 15), and the Rth retardation was 35 nm (Rth^1 = 35).

The optical compensatory sheet (1) was vertically sliced along the rubbing direction to obtain a ultra-thin section (sample). The sample was placed an atmosphere of OsO_4 for 48 hours to dye the sample. The dyed sample was observed with a transparent electron microscope (TEM) to obtain a microscopic photograph. In the sample, the acryloyl

group of the discotic compound was dyed to show an image in the photograph.

Upon checking the photograph, the discotic units in the optically anisotropic layer was inclined from the surface plane of the transparent substrate. The inclined angle continuously increased as the distance from the surface of the substrate increased.

The retardation of the optical compensatory sheet (1) was measured in the same manner as in the measurement of the optical anisotropic layer. The angle between the direction of the minimum retardation and the normal line of the sheet was 8° (β^3 = 8°), the retardation in plane was 3 nm (Re^3 = 3), and the Rth retardation was 150 nm (Rth^3 = 150).

EXAMPLE 2

On a glass place, an orientation layer was formed in the same manner as in Example 1. The formed layer was subjected to the rubbing treatment in the same manner as in Example 1. An optically anisotropic layer was formed on the orientation layer in the same manner as in Example 1.

The optically anisotropic layer was transferred to the transparent substrate used in Example 1 by using an adhesive to obtain an optical compensatory sheet (2). The rubbing direction was parallel to the slow axis of the transparent substrate.

The transparent substrate and the optically anisotropic layer were the same as those of the optical compensatory sheet (1) in Example 1. Accordingly, the optical characteristics of the transparent substrate and the optically anisotropic layer were the same as those measured in Example 1.

The optical characteristics of the optical compensatory sheet (2) were measured in the same manner as in Example 1. However, the results were the same as those of Example 1.

EXAMPLE 3

In dichloromethane, 2,2'-bis(4-hydroxyphenyl)propane polycarbonate resin (viscosity average molecular weight: 28,000) was dissolved to obtain a 18 wt.% solution. The obtained solution was cast on a band, dried at 50°C for 10 minutes, peeled from the band, and dried at 100°C for 10 minutes. The obtained film was stretched by 7% along a longitudinal direction at 170°C, and was stretched by 5% along a horizontal direction at 175°C to obtain a biaxially stretched roll film (transparent substrate) having the thickness of 100 µm. The longitudinal stretching was controlled by the difference between the rotating speeds of two chucking rolls. The horizontal stretching was controlled by the width of a tenter.

The retardation of the transparent substrate was measured by using an ellipsometer (AEP-100). The retardation in plane was -7 nm (Re^2 = 7) and the Rth retardation was 120 nm (Rth^2 = 120). The directions of nx and ny were present in the plane and the direction of nx was parallel to the normal line of the transparent substrate. The angle between the direction of the minimum retardation and the normal line of the substrate (β^2) was 0°.

An optical compensatory sheet (3) was prepared in the same manner as in Example 1, except that the above-prepared transparent substrate was used and the rubbing direction of the orientation layer was perpendicular to the slow axis of the transparent substrate. The optical characteristics of the optical compensatory sheet (3) were measured in the same manner as in Example 1. The results are set forth in Table 1.

COMPARISON EXAMPLE 1

In dichloromethane, 2,2'-bis(4-hydroxyphenyl)propane polycarbonate resin (viscosity average molecular weight: 28,000) was dissolved to obtain a 18 wt.% solution. The obtained solution was cast on a band, dried at 50°C for 10 minutes, peeled from the band, and dried at 100°C for 10 minutes. The obtained film was stretched by 12% along a longitudinal direction at 170°C, and was stretched by 14% along a horizontal direction at 175°C to obtain a biaxially stretched roll film having the thickness of 100 µm. The longitudinal stretching was controlled by the difference between the rotating speeds of two chucking rolls. The horizontal stretching was controlled by the width of a tenter.

The retardation of the film was measured by using an ellipsometer (AEP-100). The retardation in plane was 5 nm (Re^2 = 5) and the Rth retardation was 270 nm (Rth^2 = 270). The directions of nx and ny were present in the plane and the direction of nx was parallel to the normal line of the transparent substrate. The angle between the direction of the minimum retardation and the normal line of the substrate (β^2) was 0°.

The obtained film itself was used as an optical compensatory sheet (x).

EXAMPLE 4

In dichloromethane, 2,2'-bis(4-hydroxyphenyl)propane polycarbonate resin (viscosity average molecular weight: 28,000) was dissolved to obtain a 18 wt.% solution. The obtained solution was cast on a band, dried at 50°C for 10 minutes, peeled from the band, and dried at 100°C for 10 minutes. The obtained film was stretched by 13% along a longi-

tudinal direction at 170°C, and was stretched by 9% along a horizontal direction at 175°C to obtain a biaxially stretched roll film (transparent substrate) having the thickness of 100 μm. The longitudinal stretching was controlled by the difference between the rotating speeds of two chucking rolls. The horizontal stretching was controlled by the width of a tenter.

The retardation of the transparent substrate was measured by using an ellipsometer (AEP-100). The retardation in plane was -24 nm (Re^2 = 24) and the Rth retardation was 120 nm (Rth^2 = 120). The directions of nx and ny were present in the plane and the direction of nx was parallel to the normal line of the transparent substrate. The angle between the direction of the minimum retardation and the normal line of the substrate (β^2) was 0°.

The transparent substrate was surface treated in the same manner as in Example 1. Further, an adhesive layer and an orientation layer was formed on the transparent substrate in the same manner as in Example 1.

In 6.996 g of methyl ethyl ketone, 3.06 g of the discotic (liquid crystal) compound used in Example 1, 0.34 g of trimethylolpropane triacrylate denatured with ethylene oxide (V#360, Osaka Organic Chemical Co., Ltd.), 0.068 g of cellulose acetate butyrate (CAB551-0.2, Eastman Chemical), 0.102 g of a photopolymerization initiator (Irgacure 907, Ciba-Geigy) and 0.034 g of a sensitizer (Kayacure DETX, Nippon Kayaku Co., Ltd.) were dissolved to prepare a coating solution. The coating solution was coated on the orientation layer by using a wire bar of #3.0. The sheet was adhered to a metal frame, and heated in a thermostat at 130°C for 2 minutes to align the discotic compound. The sheet was irradiated with an ultraviolet ray at 130°C for 1 minutes by using a high pressure mercury lamp of 120 W/cm. The sheet was cooled to room temperature to obtain an optical compensatory sheet (4).

The retardation of the optically anisotropic layer was measured in the same manner as in Example 1. The angle between the direction of the minimum retardation and the normal line of the sheet was 35° (β^1 = 35°). The retardation in plane was 30 nm (Re^1 = 30), and the Rth retardation was 70 nm (Rth^1 = 70).

Further, the optical characteristics of the optical compensatory sheet (4) were measured in the same manner as in Example 1. The results are set forth in Table 1.

EXAMPLE 5

On a glass place, an orientation layer was formed in the same manner as in Example 1. The formed layer was subjected to the rubbing treatment in the same manner as in Example 1. An optically anisotropic layer was formed on the orientation layer in the same manner as in Example 4.

The optically anisotropic layer was transferred to the transparent substrate used in Example 4 by using an adhesive to obtain an optical compensatory sheet (5). The rubbing direction was parallel to the slow axis of the transparent substrate.

The transparent substrate and the optically anisotropic layer were the same as those of the optical compensatory sheet (4) in Example 4. Accordingly, the optical characteristics of the transparent substrate and the optically anisotropic layer were the same as those measured in Example 4.

The optical characteristics of the optical compensatory sheet (5) were measured in the same manner as in Example 1. However, the results were the same as those of Example 4.

EXAMPLE 6

Three sheets of triacetyl cellulose film (Fujitac, Fuji Photo Film Co., Ltd.) were laminated with an adhesive. The machine directions of the sheets were in parallel with each other. The lamination was used as a transparent substrate.

The retardation of the transparent substrate was measured by using an ellipsometer (AEP-100). The retardation in plane was -13 nm (Re^2 = 13) and the Rth retardation was 120 nm (Rth^2 = 120). The directions of nx and ny were present in the plane and the direction of nx was parallel to the normal line of the transparent substrate. The angle between the direction of the minimum retardation and the normal line of the substrate (β^2) was 0°.

An optical compensatory sheet (6) was prepared in the same manner as in Example 4, except that the above-prepared transparent substrate was used. The optical characteristics of the optical compensatory sheet (6) were measured in the same manner as in Example 1. The results are set forth in Table 1.

TABLE 1

Sample	Anisotropic layer				Substrate			OC sheet		
	Form	β^1	Re^1	Rth^1	β^2	Re^2	Rth^2	β^3	Re^3	Rth^3
(1)	C	28°	15	35	0°	12	120	8°	3	150
(2)	T	28°	15	35	0°	12	120	8°	3	150

TABLE 1 (continued)

Sample	Anisotropic layer				Substrate			OC sheet		
	Form	β^1	Re^1	Rth^1	β^2	Re^2	Rth^2	β^3	Re^3	Rth^3
(3)	C	28°	15	35	0°	7	120	8°	8	150
(x)	None				0°	5	280	0°	5	280
(4)	C	35°	30	70	0°	24	240	8°	6	300
(5)	T	35°	30	70	0°	24	240	8°	6	300
(6)	C	35°	15	35	0°	13	120	8°	2	300

(Remark)
Form: An optically anisotropic layer formed by coating (C) or transferring (T) method
OC sheet: Optical compensatory sheet

EXAMPLE 11

(Preparation of liquid crystal cell)

To a 3 wt.% aqueous solution of polyvinyl alcohol, 1 wt.% of octadecyldimethylammonium chloride (coupling agent) was added. The mixture was coated on a glass plate having an ITO electrode by using a spin coater. After heating the coating layer at 160°C, the layer was subjected to a rubbing treatment to form an orientation layer for vertical alignment. The orientation layers were formed on two glass plates. The rubbing direction on one glass plate was reverse to the rubbing direction on the other plate. The two glass plates were placed by facing the orientation layer with each other. The cell gap (d) was 5.5 µm. A liquid crystal molecule (Δn: 0.05) comprising an ester liquid crystal molecule and an ethane liquid crystal molecule was injected into the cell gap to prepare a liquid crystal cell of a vertical alignment mode. The product of Δn and d was 275 nm.

(Preparation of liquid crystal display)

Two optical compensatory sheets (1) was arranged on both sides of the liquid crystal cell of a vertical alignment mode. The optically anisotropic layer of the optical compensatory sheet was faced with the glass plate of the liquid crystal cell. The rubbing direction of the orientation layer of the liquid crystal cell was reversely parallel to the rubbing direction of the orientation layer of the optical compensatory sheet. Two polarizing elements were arranged on the optical compensatory sheet according to a crossed nicols arrangement.

Voltage of a square wave was applied to the liquid crystal cell of the vertical alignment mode. An image was displayed according to an NB mode (black: 2V, white: 6V). A ratio of the transmittance (white/black) was measured as a contrast ratio. The upward, downward, leftward and rightward contrast ratios were measured by using a meter (EZ-Contrast 160D, ELDIM). The results are set forth in Table 2.

EXAMPLE 12

Two optical compensatory sheets (1) was arranged on both sides of the liquid crystal cell of a vertical alignment mode used in Example 11. The transparent substrate of the optical compensatory sheet was faced with the glass plate of the liquid crystal cell. The rubbing direction of the orientation layer of the liquid crystal cell was parallel to the rubbing direction of the orientation layer of the optical compensatory sheet. Two polarizing elements were arranged on the optical compensatory sheet according to a crossed nicols arrangement.

Voltage of a square wave was applied to the liquid crystal cell of the vertical alignment mode. An image was displayed according to an NB mode (black: 2V, white: 6V). A ratio of the transmittance (white/black) was measured as a contrast ratio. The upward, downward, leftward and rightward contrast ratios were measured by using a meter (EZ-Contrast 160D, ELDIM). The results are set forth in Table 2.

EXAMPLE 13

Two optical compensatory sheets (2) was arranged on both sides of the liquid crystal cell of a vertical alignment mode used in Example 11. The optically anisotropic layer of the optical compensatory sheet was faced with the glass plate of the liquid crystal cell. The rubbing direction of the orientation layer of the liquid crystal cell was parallel to the

rubbing direction of the orientation layer of the optical compensatory sheet Two polarizing elements were arranged on the optical compensatory sheet according to a crossed nicols arrangement.

Voltage of a square wave was applied to the liquid crystal cell of the vertical alignment mode. An image was displayed according to an NB mode (black: 2V, white: 6V). A ratio of the transmittance (white/black) was measured as a contrast ratio. The upward, downward, leftward and rightward contrast ratios were measured by using a meter (EZ-Contrast 160D, ELDIM). The results are set forth in Table 2.

EXAMPLE 14

Two optical compensatory sheets (2) was arranged on both sides of the liquid crystal cell of a vertical alignment mode used in Example 11. The transparent substrate of the optical compensatory sheet was faced with the glass plate of the liquid crystal cell. The rubbing direction of the orientation layer of the liquid crystal cell was reversely parallel to the rubbing direction of the orientation layer of the optical compensatory sheet. Two polarizing elements were arranged on the optical compensatory sheet according to a crossed nicols arrangement.

Voltage of a square wave was applied to the liquid crystal cell of the vertical alignment mode. An image was displayed according to an NB mode (black: 2V, white: 6V). A ratio of the transmittance (white/black) was measured as a contrast ratio. The upward, downward, leftward and rightward contrast ratios were measured by using a meter (EZ-Contrast 160D, ELDIM). The results are set forth in Table 2.

EXAMPLE 15

One optical compensatory sheet (3) was arranged on a display (observing) side of the liquid crystal cell of a vertical alignment mode used in Example 11. The optically anisotropic layer of the optical compensatory sheet was faced with the glass plate of the liquid crystal cell. The rubbing direction of the orientation layer of the liquid crystal cell was reversely parallel to the rubbing direction of the orientation layer of the optical compensatory sheet. Two polarizing elements were arranged on the liquid crystal cell and the optical compensatory sheet according to a crossed nicols arrangement.

Voltage of a square wave was applied to the liquid crystal cell of the vertical alignment mode. An image was displayed according to an NB mode (black: 2V, white: 6V). A ratio of the transmittance (white/black) was measured as a contrast ratio. The upward, downward, leftward and rightward contrast ratios were measured by using a meter (EZ-Contrast 160D, ELDIM). The results are set forth in Table 2.

COMPARISON EXAMPLE 2

One optical compensatory sheet (x) was arranged on a display (observing) side of the liquid crystal cell of a vertical alignment mode used in Example 11. The rubbing direction of the orientation layer of the liquid crystal cell was perpendicular to the slow axis of the optical compensatory sheet. Two polarizing elements were arranged on the liquid crystal cell and the optical compensatory sheet according to a crossed nicols arrangement.

Voltage of a square wave was applied to the liquid crystal cell of the vertical alignment mode. An image was displayed according to an NB mode (black: 2V, white: 6V). A ratio of the transmittance (white/black) was measured as a contrast ratio. The upward, downward, leftward and rightward contrast ratios were measured by using a meter (EZ-Contrast 160D, ELDIM). The results are set forth in Table 2.

EXAMPLE 16

One optical compensatory sheet (4) was arranged on a display (observing) side of the liquid crystal cell of a vertical alignment mode used in Example 11. The optically anisotropic layer of the optical compensatory sheet was faced with the glass plate of the liquid crystal cell. The rubbing direction of the orientation layer of the liquid crystal cell was reversely parallel to the rubbing direction of the orientation layer of the optical compensatory sheet. Two polarizing elements were arranged on the liquid crystal cell and the optical compensatory sheet according to a crossed nicols arrangement.

Voltage of a square wave was applied to the liquid crystal cell of the vertical alignment mode. An image was displayed according to an NB mode (black: 2V, white: 6V). A ratio of the transmittance (white/black) was measured as a contrast ratio. The upward, downward, leftward and rightward contrast ratios were measured by using a meter (EZ-Contrast 160D, ELDIM). The results are set forth in Table 2.

EXAMPLE 17

One optical compensatory sheet (4) was arranged on a display (observing) side of the liquid crystal cell of a vertical alignment mode used in Example 11. The transparent substrate of the optical compensatory sheet was faced with the glass plate of the liquid crystal cell. The rubbing direction of the orientation layer of the liquid crystal cell was parallel to the rubbing direction of the orientation layer of the optical compensatory sheet. Two polarizing elements were arranged on the liquid crystal cell and the optical compensatory sheet according to a crossed nicols arrangement.

Voltage of a square wave was applied to the liquid crystal cell of the vertical alignment mode. An image was displayed according to an NB mode (black: 2V, white: 6V). A ratio of the transmittance (white/black) was measured as a contrast ratio. The upward, downward, leftward and rightward contrast ratios were measured by using a meter (EZ-Contrast 160D, ELDIM). The results are set forth in Table 2.

EXAMPLE 18

One optical compensatory sheet (5) was arranged on a display (observing) side of the liquid crystal cell of a vertical alignment mode used in Example 11. The optically anisotropic layer of the optical compensatory sheet was faced with the glass plate of the liquid crystal cell. The rubbing direction of the orientation layer of the liquid crystal cell was parallel to the rubbing direction of the orientation layer of the optical compensatory sheet. Two polarizing elements were arranged on the liquid crystal cell and the optical compensatory sheet according to a crossed nicols arrangement.

Voltage of a square wave was applied to the liquid crystal cell of the vertical alignment mode. An image was displayed according to an NB mode (black: 2V, white: 6V). A ratio of the transmittance (white/black) was measured as a contrast ratio. The upward, downward, leftward and rightward contrast ratios were measured by using a meter (EZ-Contrast 160D, ELDIM). The results are set forth in Table 2.

EXAMPLE 19

One optical compensatory sheet (5) was arranged on a display (observing) side of the liquid crystal cell of a vertical alignment mode used in Example 11. The transparent substrate of the optical compensatory sheet was faced with the glass plate of the liquid crystal cell. The rubbing direction of the orientation layer of the liquid crystal cell was reversely parallel to the rubbing direction of the orientation layer of the optical compensatory sheet. Two polarizing elements were arranged on the liquid crystal cell and the optical compensatory sheet according to a crossed nicols arrangement.

Voltage of a square wave was applied to the liquid crystal cell of the vertical alignment mode. An image was displayed according to an NB mode (black: 2V, white: 6V). A ratio of the transmittance (white/black) was measured as a contrast ratio. The upward, downward, leftward and rightward contrast ratios were measured by using a meter (EZ-Contrast 160D, ELDIM). The results are set forth in Table 2.

EXAMPLE 20

One optical compensatory sheet (6) was arranged on a display (observing) side of the liquid crystal cell of a vertical alignment mode used in Example 11. The optically anisotropic layer of the optical compensatory sheet was faced with the glass plate of the liquid crystal cell. The rubbing direction of the orientation layer of the liquid crystal cell was reversely parallel to the rubbing direction of the orientation layer of the optical compensatory sheet. Two polarizing elements were arranged on the liquid crystal cell and the optical compensatory sheet according to a crossed nicols arrangement.

Voltage of a square wave was applied to the liquid crystal cell of the vertical alignment mode. An image was displayed according to an NB mode (black: 2V, white: 6V). A ratio of the transmittance (white/black) was measured as a contrast ratio. The upward, downward, leftward and rightward contrast ratios were measured by using a meter (EZ-Contrast 160D, ELDIM). The results are set forth in Table 2.

COMPARISON EXAMPLE 3

Two polarizing elements were arranged on the liquid crystal cell and the optical compensatory sheet according to a crossed nicols arrangement without using an optical compensatory sheet.

Voltage of a square wave was applied to the liquid crystal cell of the vertical alignment mode. An image was displayed according to an NB mode (black: 2V, white: 6V). A ratio of the transmittance (white/black) was measured as a contrast ratio. The upward, downward, leftward and rightward contrast ratios were measured by using a meter (EZ-Contrast 160D, ELDIM). The results are set forth in Table 2.

TABLE 2

Sample	OC sheet				α2/α1	Ratio	Viewing angle			
	(A)	(B)	(C)	Re^3			U	D	L	R
11	(1)	2	N-R	3	1.13	300	70	70	70	70
12	(1)	2	R-N	3	1.13	300	70	70	70	70
13	(2)	2	N-N	3	1.13	300	70	70	70	70
14	(2)	2	R-R	3	1.13	300	70	70	70	70
15	(3)	1	N-R	8	1.13	100	60	60	60	60
C1	(x)	1	---	5	1.01	300	40	60	60	60
16	(4)	1	N-R	6	1.13	300	70	70	70	70
17	(4)	1	R-N	6	1.13	300	70	70	70	70
18	(5)	1	N-N	6	1.13	300	70	70	70	70
19	(5)	1	R-R	6	1.13	300	70	70	70	70
20	(6)	1	N-R	2	0.72	120	60	60	60	60
C3		No OC sheet				300	30	40	40	40

(Remark)
(A): Optical compensatory sheet prepared in Examples 1 to 6 and Comparison Example 1 (x)
(B): Number of optical compensatory sheet(s) used in a liquid crystal display
(C): Arrangement of an optical compensatory sheet, which indicates whether an optically anisotropic layer (N) or a transparent substrate (R) is faced with a glass plate, and (-) whether the rubbing direction of the liquid crystal cell is parallel (N) or reversely parallel (R) to the rubbing direction of the optical compensatory sheet
Ratio: Contrast ratio (white/black)
Viewing angle: An angle that can view an image having a contrast ratio of not smaller than 10 along upward (U), downward (D), leftward (L) or rightward (R) direction

Claims

1. A liquid crystal display comprising a liquid crystal cell of a vertical alignment mode, two optical compensatory sheets arranged on both sides of the liquid crystal cell and two polarizing elements arranged on the optical compensatory sheets, said liquid crystal cell containing liquid crystal molecules, which are essentially vertically aligned while not applying voltage to the cell, and are essentially horizontally aligned while applying voltage to the cell,

   wherein each of the optical compensatory sheets comprises a transparent substrate and an optically anisotropic layer containing a discotic compound, said optically anisotropic layer having an optical anisotropy to optically compensate an optical anisotropy of the liquid crystal cell while applying voltage to the cell, and each of said optical compensatory sheets having a retardation value in plane in the range of -5 to 5 nm.

2. The liquid crystal display as defined in claim 1, wherein the optically anisotropic layer and the transparent substrate are so arranged that a slow axis of the optically anisotropic layer is essentially perpendicular to a slow axis of the transparent substrate, and each of the optically anisotropic layer and the transparent substrate has retardation in plane satisfying the following formula:

$$|Re^1 - Re^2| \leq 5 \text{ nm}$$

   in which Re^1 is an absolute retardation value in plane of the optically anisotropic layer and Re^2 is an absolute retardation value in plane of the transparent substrate.

3. The liquid crystal display as defined in claim 1, wherein each of the liquid crystal cell and the optical compensatory sheet has a degree of a wavelength dispersion satisfying the following formula:

$$0.8 \leq \alpha 2/\alpha 1 \leq 1.3$$

in which $\alpha 1$ is a degree of a wavelength dispersion of the liquid crystal cell, which is a ratio of a retardation value of the cell at the wavelength of 450 nm to a retardation value of the cell at the wavelength of 550 nm, and $\alpha 2$ is a degree of a wavelength dispersion of the optical compensatory sheet, which is a ratio of a retardation value of the sheet at the wavelength of 450 nm to a retardation value of the sheet at the wavelength of 550 nm.

4. The liquid crystal display as defined in claim 1, wherein the liquid crystal molecule has a negative dielectric anisotropy.

5. The liquid crystal display as defined in claim 1, wherein the transparent substrate is a biaxially stretched polymer film.

6. The liquid crystal display as defined in claim 1, wherein the discotic compound is aligned and fixed in the optically anisotropic layer.

7. A liquid crystal display comprising a liquid crystal cell of a vertical alignment mode, an optical compensatory sheets arranged on one side of the liquid crystal cell and two polarizing elements arranged on the liquid crystal cell and the optical compensatory sheet, said liquid crystal cell containing liquid crystal molecules, which are essentially vertically aligned while not applying voltage to the cell, and are essentially horizontally aligned while applying voltage to the cell,

wherein the optical compensatory sheet comprises a transparent substrate and an optically anisotropic layer containing a discotic compound, said optically anisotropic layer having an optical anisotropy to optically compensate an optical anisotropy of the liquid crystal cell while applying voltage to the cell, and said optical compensatory sheet having a retardation value in plane in the range of -10 to 10 nm.

8. The liquid crystal display as defined in claim 7, wherein the optically anisotropic layer and the transparent substrate are so arranged that a slow axis of the optically anisotropic layer is essentially perpendicular to a slow axis of the transparent substrate, and each of the optically anisotropic layer and the transparent substrate has retardation in plane satisfying the following formula:

$$|Re^1 - Re^2| \leq 10 \text{ nm}$$

in which Re^1 is an absolute retardation value of the optically anisotropic layer in plane and Re^2 is an absolute retardation value of the transparent substrate in plane.

9. The liquid crystal display as defined in claim 7, wherein each of the liquid crystal cell and the optical compensatory sheet has a degree of a wavelength dispersion satisfying the following formula:

$$0.8 \leq \alpha 2/\alpha 1 \leq 1.3$$

in which $\alpha 1$ is a degree of a wavelength dispersion of the liquid crystal cell, which is a ratio of a retardation value of the cell at the wavelength of 450 nm to a retardation value of the cell at the wavelength of 550 nm, and $\alpha 2$ is a degree of a wavelength dispersion of the optical compensatory sheet, which is a ratio of a retardation value of the sheet at the wavelength of 450 nm to a retardation value of the sheet at the wavelength of 550 nm.

10. The liquid crystal display as defined in claim 7, wherein the liquid crystal molecule has a negative dielectric anisotropy.

11. The liquid crystal display as defined in claim 7, wherein the transparent substrate is a biaxially stretched polymer film.

12. The liquid crystal display as defined in claim 7, wherein the discotic compound is aligned and fixed in the optically anisotropic layer.

13. An optical compensatory sheet comprising a transparent substrate and an optically anisotropic layer containing a discotic compound,

wherein the optically anisotropic layer and the transparent substrate are so arranged that a slow axis of the

optically anisotropic layer is essentially perpendicular to a slow axis of the transparent substrate, and each of the optically anisotropic layer and the transparent substrate has retardation in plane satisfying the following formula:

$$|Re^{1}-Re^{2}| \leq 10 \text{ nm}$$

in which Re^1 is an absolute retardation value in plane of the optically anisotropic layer and Re^2 is an absolute retardation value in plane of the transparent substrate.

14. The optical compensatory sheet as defined in claim 13, wherein the optical compensatory sheet has a retardation in plane in the range of -10 to 10 nm.

15. The optical compensatory sheet as defined in claim 13, wherein the minimum retardation value of the optically anisotropic layer is larger than 0.

16. The optical compensatory sheet as defined in claim 13, wherein the optical compensatory sheet has a direction of the minimum retardation, and an angle between the direction and a normal line of the sheet is in the range of 0 to 50°.

17. The optical compensatory sheet as defined in claim 13, wherein the optical compensatory sheet has a Rth retardation value defined by the following formula in the range of 10 to 600 nm:

$$Rth = |[\{(n1+n2)/2\}-n3]\times d|$$

in which each of n1, n2 and n3 is the principal refractive index in a refractive index ellipsoid approximately obtained from an optical anisotropy of the optical compensatory sheet, n3 is the minimum index, and d is the thickness of the optical compensatory sheet.

18. The optical compensatory sheet as defined in claim 13, wherein the transparent substrate is a biaxially stretched polymer film.

19. The optical compensatory sheet as defined in claim 13, wherein the discotic compound is aligned and fixed in the optically anisotropic layer.

FIG. 1

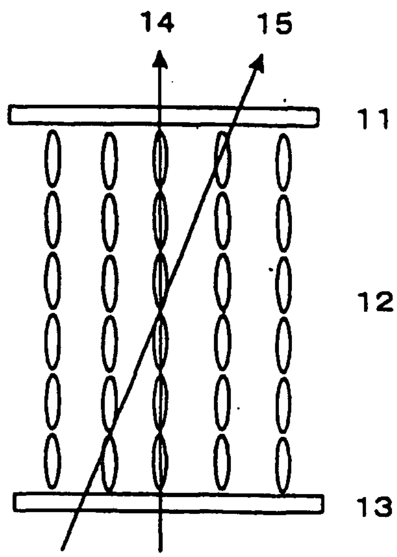


FIG. 2

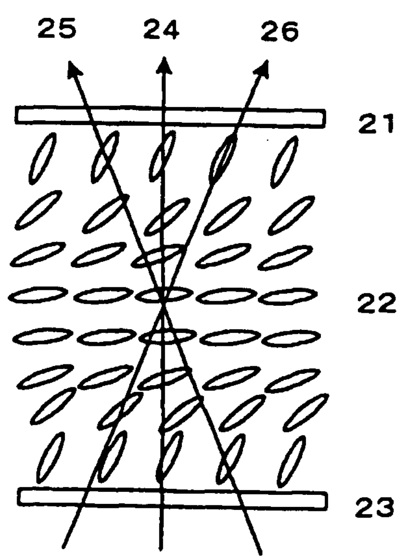


FIG. 3

(a) (b)

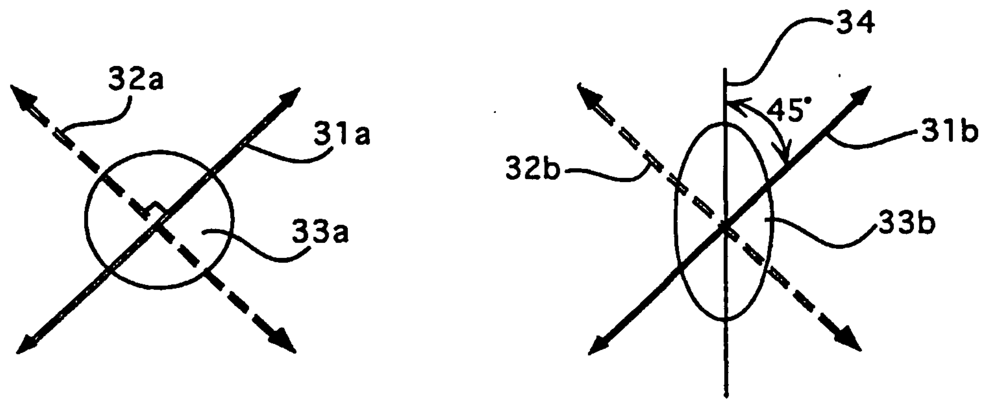


FIG. 4

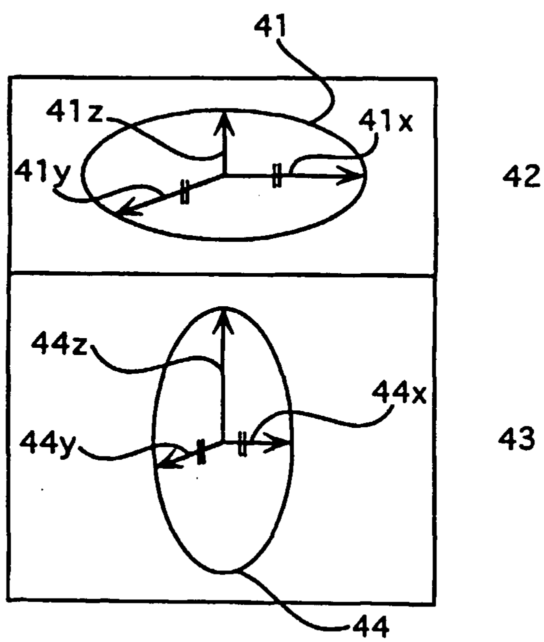


FIG. 5

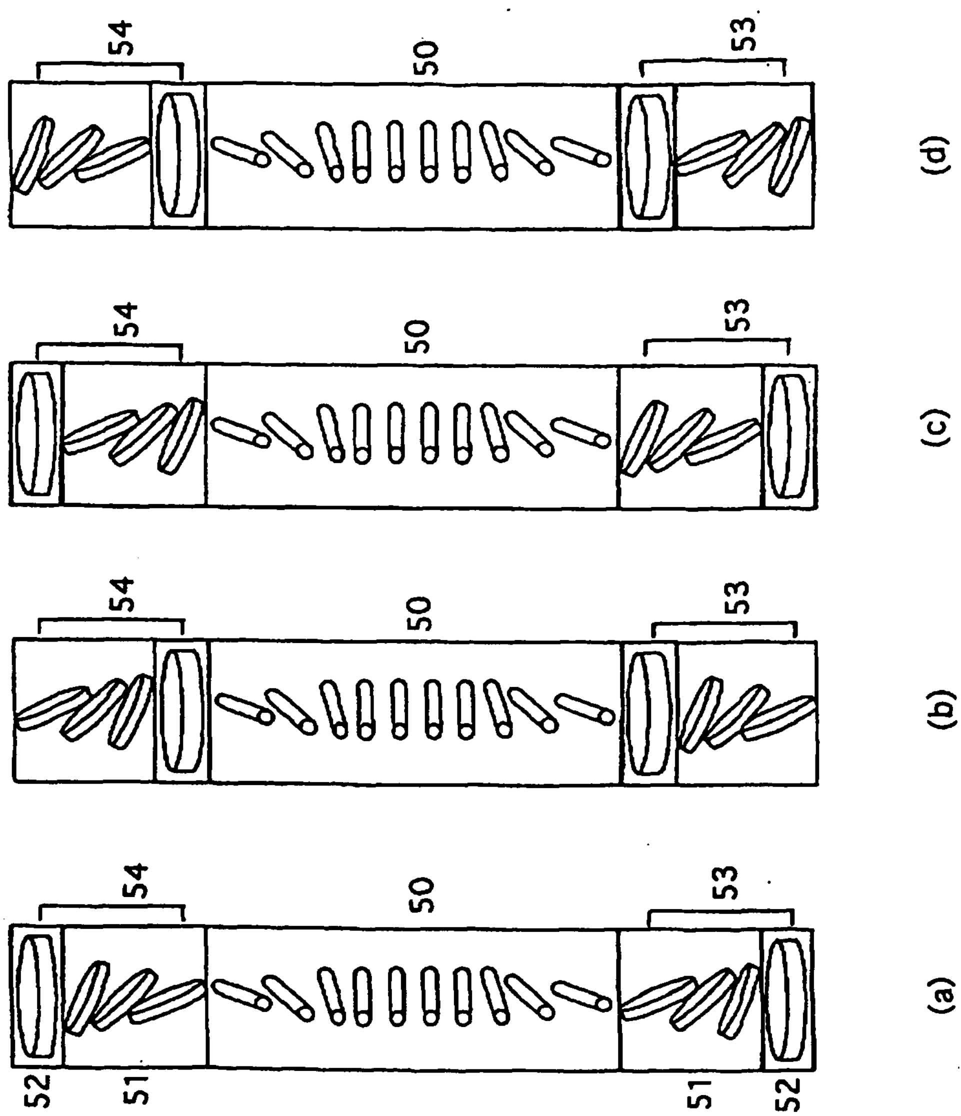


FIG. 6

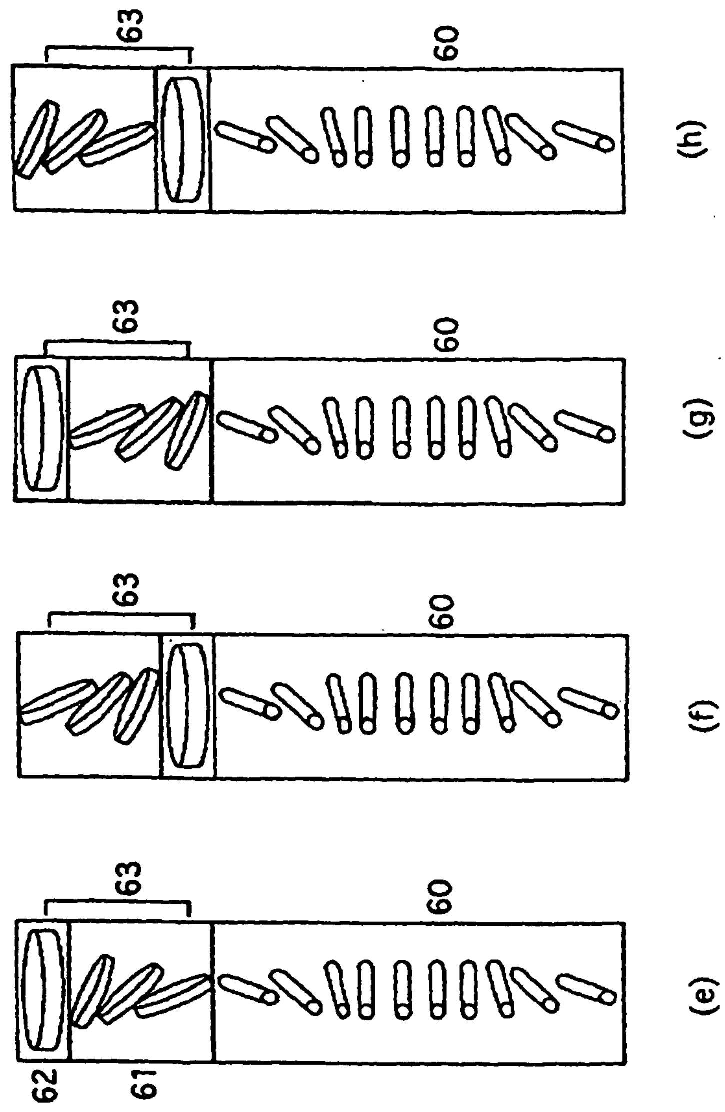


FIG. 7

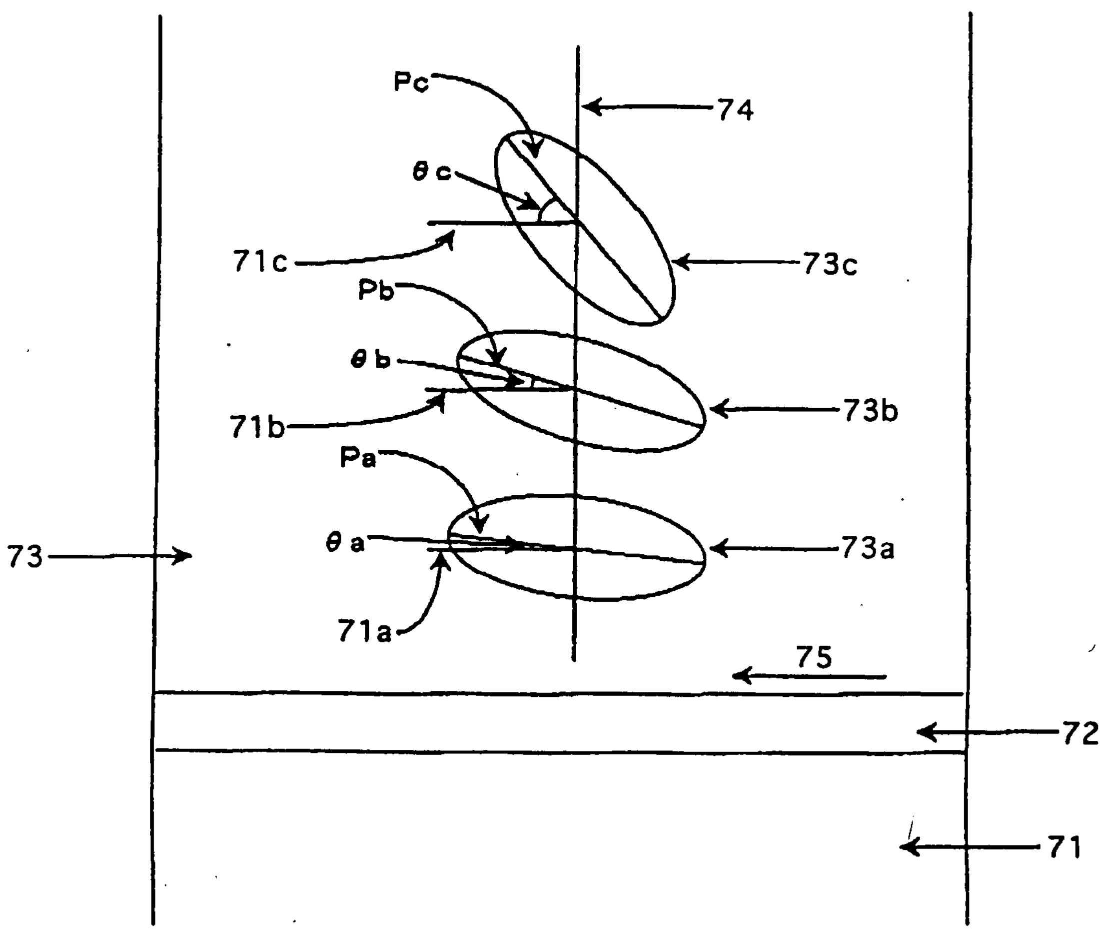
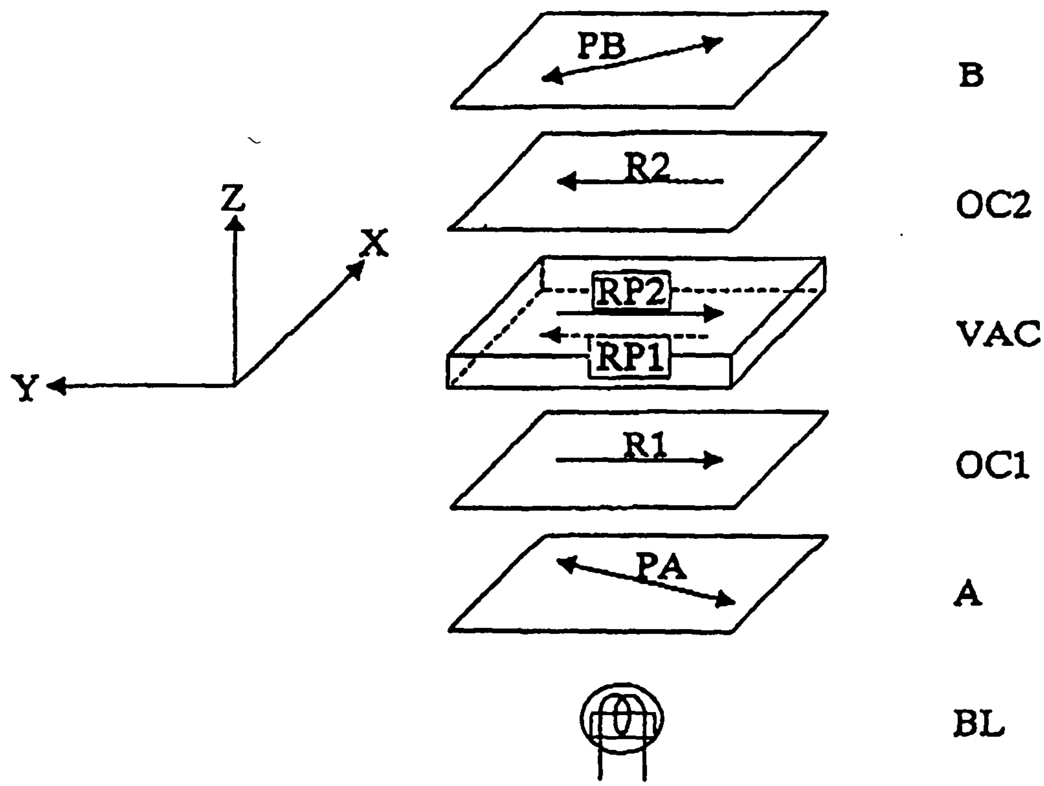


FIG. 8



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EUROPEAN SEARCH REPORT

Application Number
EP 98 10 4264

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	US 5 528 400 A (ARAKAWA KOHEI) 18 June 1996 * column 5, line 18 - column 8, line 67 * ---	1,2,5-8, 10-16	G02F1/1335 G02B5/30 G02F1/139
A	WO 96 37804 A (NIPPON OIL CO LTD ;MAZAKI HITOSHI (JP); SATO YASUSHI (JP); TOYOOKA) 28 November 1996 -& EP 0 783 128 A * page 2 - page 4, line 26; figures 1-18 * ---	1,6,7, 12,13,16	
A	SHIN-TSON WU: "FILM-COMPENSATED HOMEOTROPIC LIQUID-CRYSTAL CELL FOR DIRECT VIEW DISPLAY" JOURNAL OF APPLIED PHYSICS, vol. 76, no. 10, PART 01, 15 November 1994, pages 5975-5980, XP000491748 *sections IIA, IIIA, IIIB * * figures 1,4-6 * ---	3,7,9,10	
A	EP 0 350 382 A (STANLEY ELECTRIC CO LTD ;UCHIDA TATSUO (JP); COMMISSARIAT ENERGIE) 10 January 1990 * the whole document * ---	1,4,7,10	**TECHNICAL FIELDS SEARCHED (Int.Cl.6)** G02F G02B
A	EP 0 162 775 A (COMMISSARIAT ENERGIE ATOMIQUE) 27 November 1985 * page 8, line 30 - page 15, line 20; figures 4-8 * ---	1,4-7, 10-15	
A	EP 0 481 489 A (STANLEY ELECTRIC CO LTD) 22 April 1992 * page 3, line 16 - line 31 * * page 4 - page 6; figures 1,4 * -----	7,10,11	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	2 June 1998	Stang, I

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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